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NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

# TECHNICAL REPORT

REPORT NO: NAWCADPAX/TR-2005/230

# THE POTENTIAL EFFECT OF MATURING TECHNOLOGY UPON FUTURE SEAPLANES

**by**


**Mr. August Bellanca**
**Ms. Carey Matthews**


**April 2005**

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# EXECUTIVE SUMMARY

This study identifies viable, existing technologies that would potentially improve seaplane performance and evaluate the impact of the technology on seaplane design. Three conceptual seaplanes were created as the baseline for comparison. Two technology areas for drag reduction were investigated. The first area investigated the effect that the seaplane step has during the cruise portion of the flight. This was done by calculating the drag and performance of a seaplane with a fixed step and with a retractable step. The second area focused on weight reduction and improved aerodynamic performance through the use of an all composite structure. Other areas of interest included the effects to takeoff gross weight if the design payload or the design range was increased or decreased. The results and conclusions of this study can be found in sections 4 and 5 in this report. A brief discussion of additional technologies to be studied can be found in section 6 of this report.

# 1.0 BACKGROUND

The Naval Surface Warfare Center, Carderock Division (NSWCCD) has tasked the NAVAIR Advanced Airborne Systems Design (AASD), Patuxent River MD, formerly the Aircraft Conceptual Design Branch, Warminster PA, to study the potential applications for future seaplane designs to fulfill the cargo transport role within the emerging Sea Base Concept of Operations. To assess the future viability of seaplanes, NSWCCD required a study that will forecast the potential effect of maturing technology upon future seaplanes.

The seaplane designs to be used as a base of study were designed by the Aircraft Conceptual Design Branch in 1994 and at the Advanced Airborne Systems Design, in 2004. The designs were as follows:

1. Battleforce Seaplane (BFS)-1.0 M lb. seaplane designed in 1994 with a gross take-off weight of 1,000,000 lbs.
2. Battleforce Seaplane (BFS)-2.9 M lb. seaplane designed in 1994 with a gross take-off weight of 2,923,000 lbs.
3. Battleforce Seaplane (BFS)-0.3 M lb. seaplane designed in 2004 with a gross take-off weight of 260,000 lbs.

The BFS-1.0 M lb. and the BFS-2.9 M lb. were designed for the Office of Naval Research and the 0.3 M lb. seaplane was designed for the Naval Surface Warfare Center, Carderock, MD. See Figure 1 for a conceptual drawing of the BFS-2.9 M lb. seaplane in flight escorted by two F-18C's.

The 2.9 M lb. seaplane and 1.0 M lb. seaplanes were envisioned in 1993 when Congress had mandated the Defense Advanced Research Projects Agency (DARPA) to investigate "very large ground effect aircraft". This was in reaction to the Russian "Wingship" project. The Wingship was a flying boat designed to carry troops across oceans at a speed of 400 mph. The Wingship concept was actually a flying winged ship to attempt to replace the slow ships that travel about 30 mph. The Wingship was to fly in ground effect, i.e. about 50 ft. above the ocean surface, and obtain efficiencies from the interaction of the cushion of air between the wing and sea surface. During a flight test, the prototype crashed and was sunk in the Caspian Sea, killing the pilots. A wing-in-ground effect aircraft proved to be impractical, although the idea of being able to transport a large group of soldiers and equipment from one destination to another quickly is still an important issue. This situation prompted the Conceptual Design Branch to propose and design a seaplane to fill this capability and still be able to fly at a high altitude over mountainous terrain. The Naval Aviation Warfare Center – Aircraft Division (NAWCAD) internally funded a counterpoint study to compare improved and advanced state of the art seaplane designs with the "revolutionary" Wingship. The two seaplane designs, the BFS 2.9 M lb. and the BFS 1.0 M lb., were created.

The design philosophy applied to these aircraft were as follows:

1. Apply all the applicable current, low risk technology to the designs
2. For low risk assumption, use design concept technology that already were successfully in use. Examples include the Russian Albatross (circa 1990's) seaplane for rescue and the Navy Martin P6-M Seamaster bomber type seaplane.

The BFS seaplane proportions were very similar to these aircraft, except expanded to carry more payload.

**Figure 1. BFS-2.9 M lb. seaplane in flight escorted by two F-18C's**

## 1.1 ADVANTAGES/USES OF A MILITARY SEAPLANE

In the 1940's the reliability of propulsion increased to a point that the favor of seaplanes declined from a military standpoint. However, military application of seaplanes has the following advantages:

1. Water covers approximately 75% of the world surface area.
    a. Water runways are maintenance free and bombproof; landing is condition dependent only.
    b. Rent free
2. No basing rights issues
3. Direct support to littoral operation
4. Aircraft size is not limited by airport constraints
    a. Mission requirements can define optimal size

    b. Runway length is not important, except distances from obstacles with rivers and lakes
    c. Seaplane design has expanded through the use of more powerful jet engines instead of reciprocating engines. Reciprocating engines require more water clearance because of the prop radius. This required elevation for reciprocating engines increases the hull depth and also increases the drag.
5. Offload support aircraft from the carrier deck, see Figure 2
6. Quick response amphibious assault ship
7. Civilian applications
    a. Rescue
    b. Fire suppression
    c. Transport
    d. Leisure

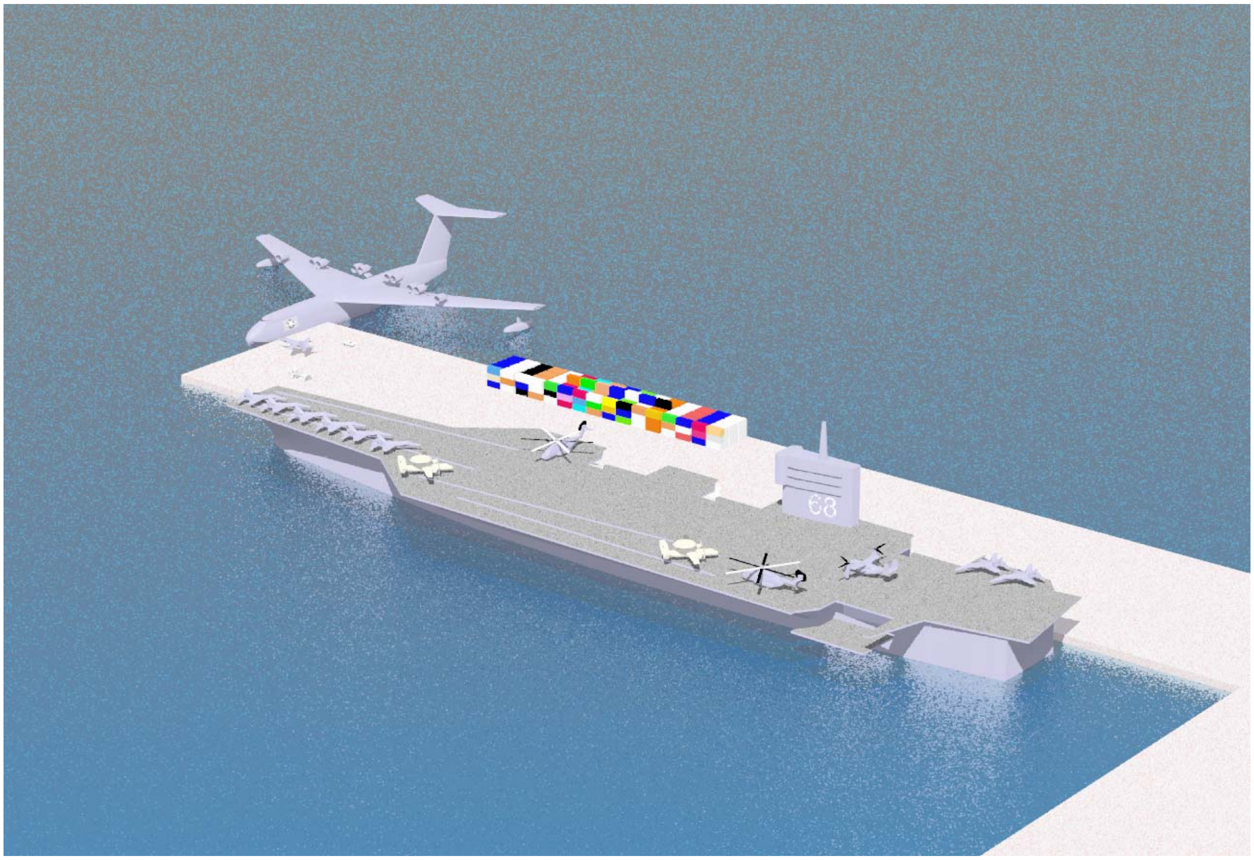


**Figure 2. Concept of Operations for the BFS 2.9 M lb. pulling into port to transport a damaged F-18C to a repair facility.**

# 2.0 APPROACH

The intent of this study, as stated in the statement of work, is to determine "application of future seaplane designs to fulfill the cargo transport role within the emerging Sea Base concept of Operations". This paper studies potential improvements in the design of the seaplane. It considers aerodynamic improvement and weight improvement. The aerodynamic improvement focused on the effect of the step drag on the seaplane on performance. This effect was studied through comparison of the drag and resulting performance for a seaplane with a fixed step design and with a retractable step. By considering the extremes of the step and the retracted step conditions, design bounds can be drawn for step improvements. The other improvement possibility is in the weight. The seaplane hull is naturally heavy because of having to be seaworthy. Here it was decided to study the most effective way to reduce weight through the use of advanced composites. The report is divided into two cases, the base case and the improved case. The improved case shows the overlay of the base case performance with the improvement.

The BFS -1.0 M lb. seaplane and the BFS -2.9 M lb. seaplane were not designed for sea basing. They were designed for a different mission. The mission of these aircraft was to carry large numbers of troops directly from CONUS to the littoral war zone. Specifically the seaplanes were to land in the water, taxi to the beach where the soldiers and tanks would embark to the beach rapidly through a door ramp in the nose. Even though these two seaplanes were designed for a different mission, the designs can be modified to include amphibious landing gear. The two large seaplanes were still deemed adequate models for this application of sea basing, without the landing gear. The latest design, BFS 0.3 M lb. seaplane, was designed to the sea-basing concept. This seaplane was designed as an amphibian; capable of landing on water and taxing up on a submerged ramp with landing gear.

The designs for the BFS 1.0 M lb. seaplane and the 2.9 M lb. seaplane were designed as follows:

1. Sought out weight fraction data for past and current seaplanes. Data and reports were obtained from a variety of sources such as Martin Aircraft Company, Naval Surface Warfare Center, the Stevens Institute of Technology, NASA, Naval Technical Intelligence Center, and Jane's All the World's Aircraft.
2. Data was obtained relative to large transport aircraft
3. Mission requirements were studied
   The seaplane mission was for a transatlantic beachable assault aircraft; the seaplane was to carry several M60 tanks or 3000 troops
4. The hull design was referenced to the existing and very successful Beriev A-46 seaplane and the Martin P6-M Seamaster
5. Used latest turbofan engines in the 90,000 – 100, 000 lb. thrust class
6. Three view drawing, weight sizing, a complete aerodynamic analysis, and initial performance estimation were performed for each seaplane.
7. Traditional construction was used for low risk and availability of information.

The approach to the design of the smaller 0.3 M lb. seaplane was simpler.   The time constraints did not allow a thorough drag calculation.  The drag calculation was estimated from a factor of flat plate equivalent parasite area ($ft^2$) versus wetted area for classes of aircraft similar to the aircraft being studied, see Figure 19, page 34 [6].
It is also the intent as part of this report to supply NSWC with calculations, tables, and graphs to make the findings ‘transparent”.  In this way, the Conceptual Design Branch with a minimal amount of time and work can extend the data for further studies and iteration.

## 2.1 DATABASE DEVELOPEMENT

A database is an orderly assembly of reference information relative to the design being studied as comparative data to aid in a new project design.  Information to be used includes wing loading, power to weight ratios, range, cruising speed, etc.  Figure 3 shows part of the database that was developed for the BFS 2.9 M lb. and BFS 1.0 M lb. seaplanes in 1994.

# Transport/Seaplane Partial Database

| Transport Jets: | Takeoff Gross Weight (lbs) | Wing Area ($ft^2$) | Wing Loading ($lb/ft^2$) | Max T/O Thrust (lbs/engine-engines) | T/W Ratio | Velocity-Cruise (Knots) | Velocity - Stall (Knots) |
|---|---|---|---|---|---|---|---|
| Boeing 737-200 | 115,500 | 980.0 | 117.80 | 15,500 - 2 | 0.2684 | 509.22 | ? |
| Boeing 747-200B | 820,000 | 5,500.0 | 149.00 | 52,500 - 4 | 0.2561 | 523.11 | ? |
| McDonnell Douglas MD-11 | 602,500 | 3,648.0 | 165.00 | 61,500 - 3 | 0.3062 | 510.96 | ? |
| Lockheed C-5A | 728,000 | 6,200.0 | 117.00 | 41,000 - 4 | 0.2253 | 496.19 | 107.75 |
| Antonov AN-124 | 892,872 | 6,760.0 | 132.00 | 51,590 - 4 | 0.2311 | 466.64 | ? |
| Ilysushin Il-76M | 374,785 | 3,229.2 | 116.06 | 26,455 - 4 | 0.2823 | 431.88 | ? |
| **Transport Jets in Development:** | | | | | | | |
| McDonnell Douglas MD-12 | 949,000 | 5,846.0 | 162.30 | 64,000 - 4 | 0.2698 | M = 0.85 | ? |
| **Seaplanes:** | | | | | | | |
| Beriev A-40 | 189,595 | 2,152.8 | 88.07 | 26,455 - 2 | 0.2793 | 410.16 | ? |
| Martin XP6M-1 | 160,000 | 1,900.0 | 84.21 | 13,000 - 4 | 0.3250 | ? | 119.92 |
| Hughes Flying Boat | 400,000 | 11,430.0 | 35.00 | 10,000 - 8 | 0.2000 | ? | ? |
| NAWC-AD-WAR Seaplane | 2,923,076 | 24,135.0 | 95.11 | 90,000 - 8 | 0.3136 | M = 0.70 | ? |

**Figure 3. Seaplane Database for BFS 2.9 M lb. and BFS 1.0 M lb. Seaplanes**

### 2.1.1 Useful Load versus Gross Take-off Weight

The following figures illustrate parametric data that was taken from a seaplane database developed by Jesse Odedra and Geoff Hope, working for the Naval Surface Warfare Center, Carderock Division. There is a parametric trend line associated with the payload of a seaplane and its gross take-off weight. Figure 4 shows how closely the designed 0.3 M lb. seaplane approaches that trend line. Figure 5 shows how closely the 1.0 M lb. and the 2.9 M lb. seaplanes are approaching the trend line.

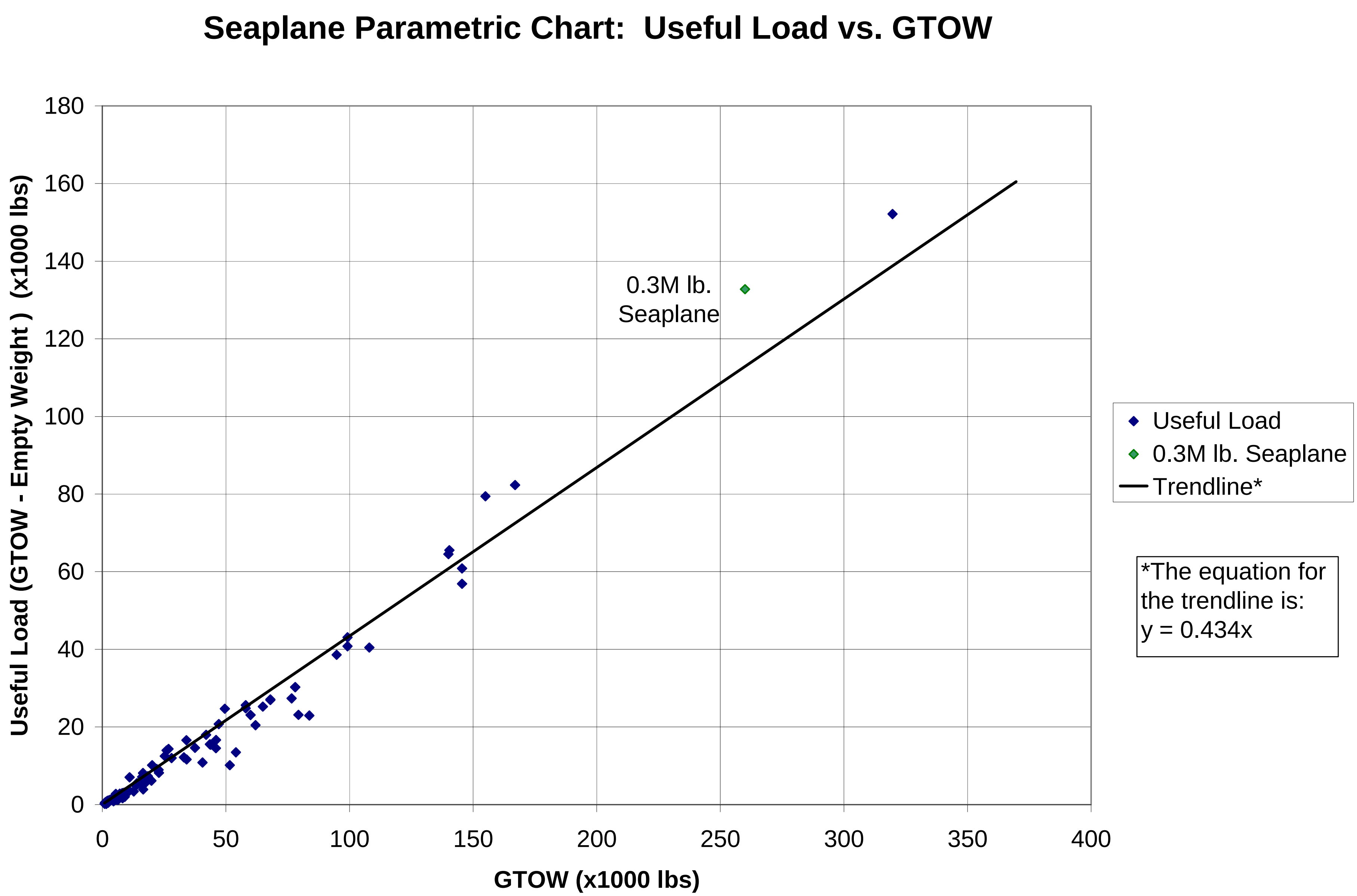



**Figure 4. Seaplane parametric chart – Useful Load vs. Gross Takeoff Weight with 0.3 M lb. Seaplane.**

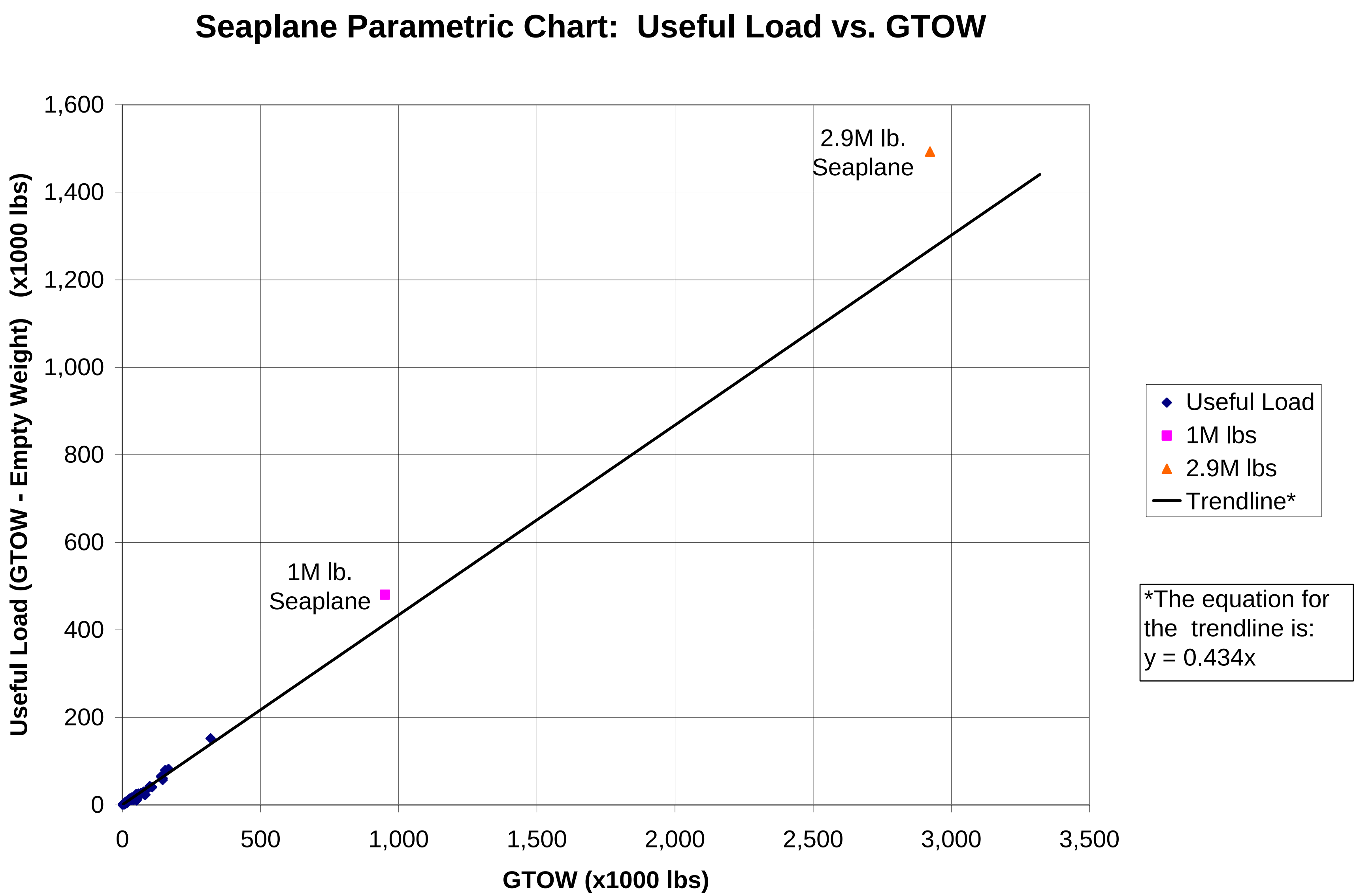



**Figure 5. Seaplane parametric chart – Useful Load vs. Gross Takeoff with BFS-1.0 M lb, 2.9 M lb. Seaplanes.**

### 2.1.2 Wing Span versus Gross Take-off Weight

Data for the wing span versus gross take-off weight parametric chart was provided by the NSWC Carderock Division. The data suggests a power curve trend line. For a gross take-off weight (GTOW) of 25,000 lb. the wing span is roughly proportional to the weight. As the weight grows to 50,000 lbs., the wing span increases about half as fast as the weight. The resulting parametric curve is shown in Figure 6 with the 0.3 M lb. seaplane plotted in relation to the data and Figure 7 with the BFS-1.0 M lb. and BFS-2.9 M lb. seaplanes plotted in relation to the data. All three seaplanes follow the trend line within a reasonable amount of variance.

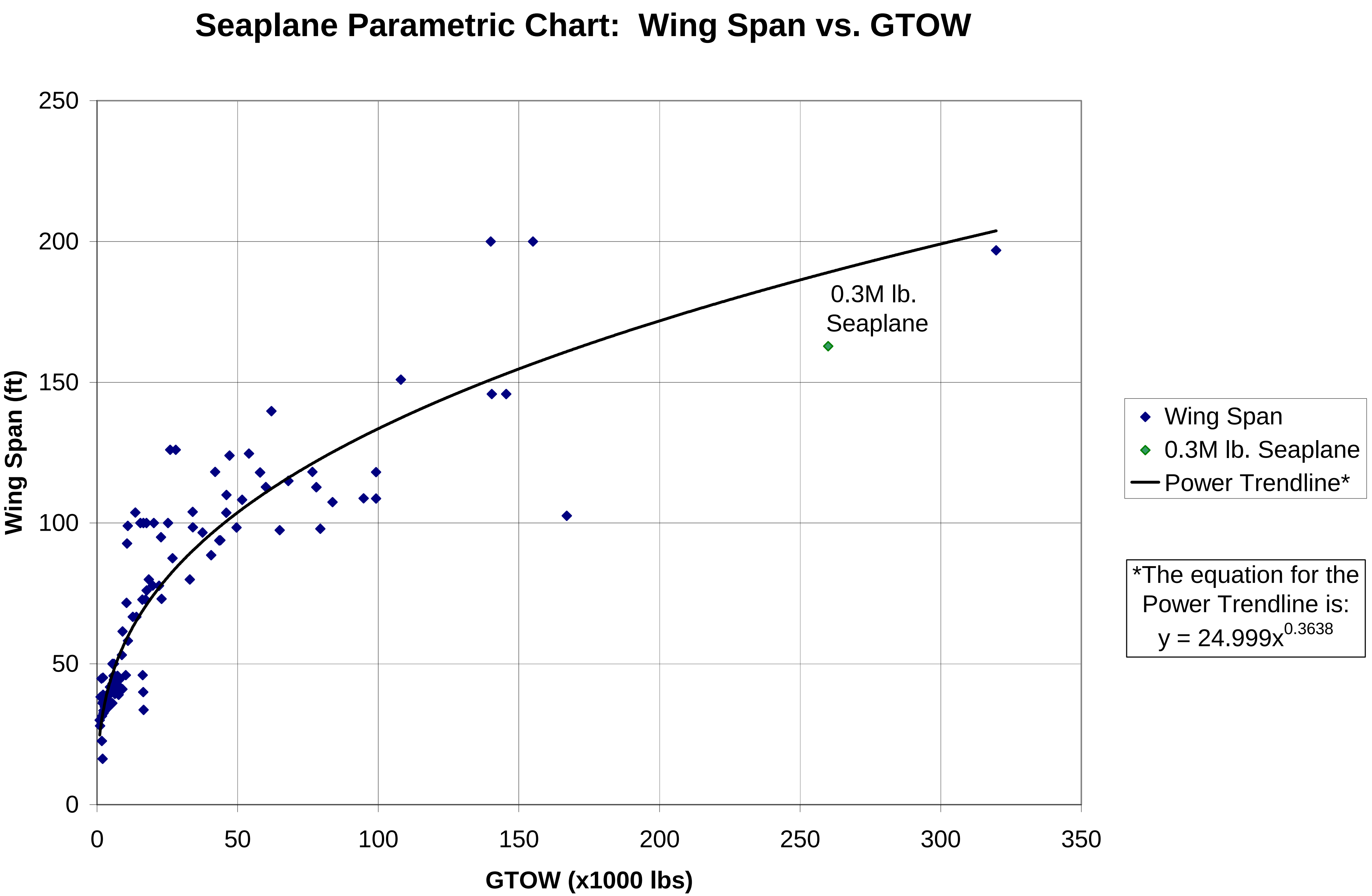



**Figure 6. Seaplane parametric chart – Wing span vs. GTOW with 0.3 M lb. Seaplane.**

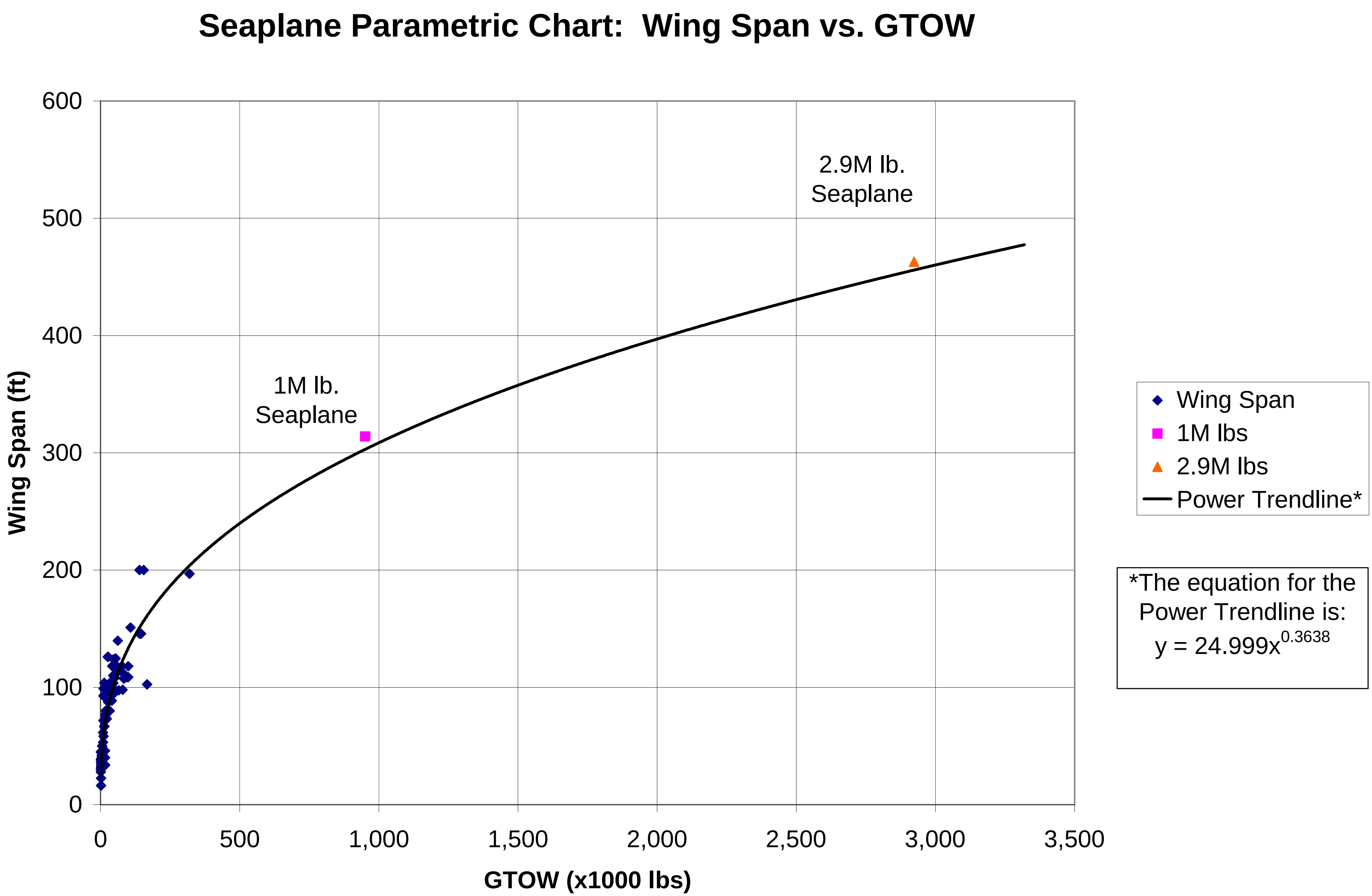



**Figure 7. Seaplane parametric chart – Wing Span vs. GTOW with BFS-1.0 M, 2.9 M lb. seaplanes.**

### 2.1.3 Fuselage Length vs. Gross Take-off Weight

Figures 8 and 9 show fuselage length versus gross take-off weight. It can be seen that BFS 1.0 M lb. and 2.9 M lb. seaplanes are in close agreement with the trend line, as is the 0.3 M lb. seaplane. More importantly, it shows an apparent power series trend line. At the beginning of the curve, up to about 250,000 lbs., the length is increasing faster than the weight. After 500,000 lbs., the weight is increasing faster than the length. Looking at the trend for various points below gives the following:

At a weight of 250,000 lbs., the length is 140 ft., or 1785 lb/ft

At a weight of 500,000 lbs., the length is 180 ft., or 2777 lb/ft.

At a weight of 1,500,000 lbs., the length is 300 ft, or 5000 lb/ft.

Figure 8 shows the 0.3 M lb. seaplane plotted in relation to the seaplane data. Figure 9 shows the BFS-1.0 M lb and 2.9 M lb. seaplanes plotted in relation to the seaplane data. The basic information for the figure was generated from seaplane data provided by NSWC, Carderock Division.

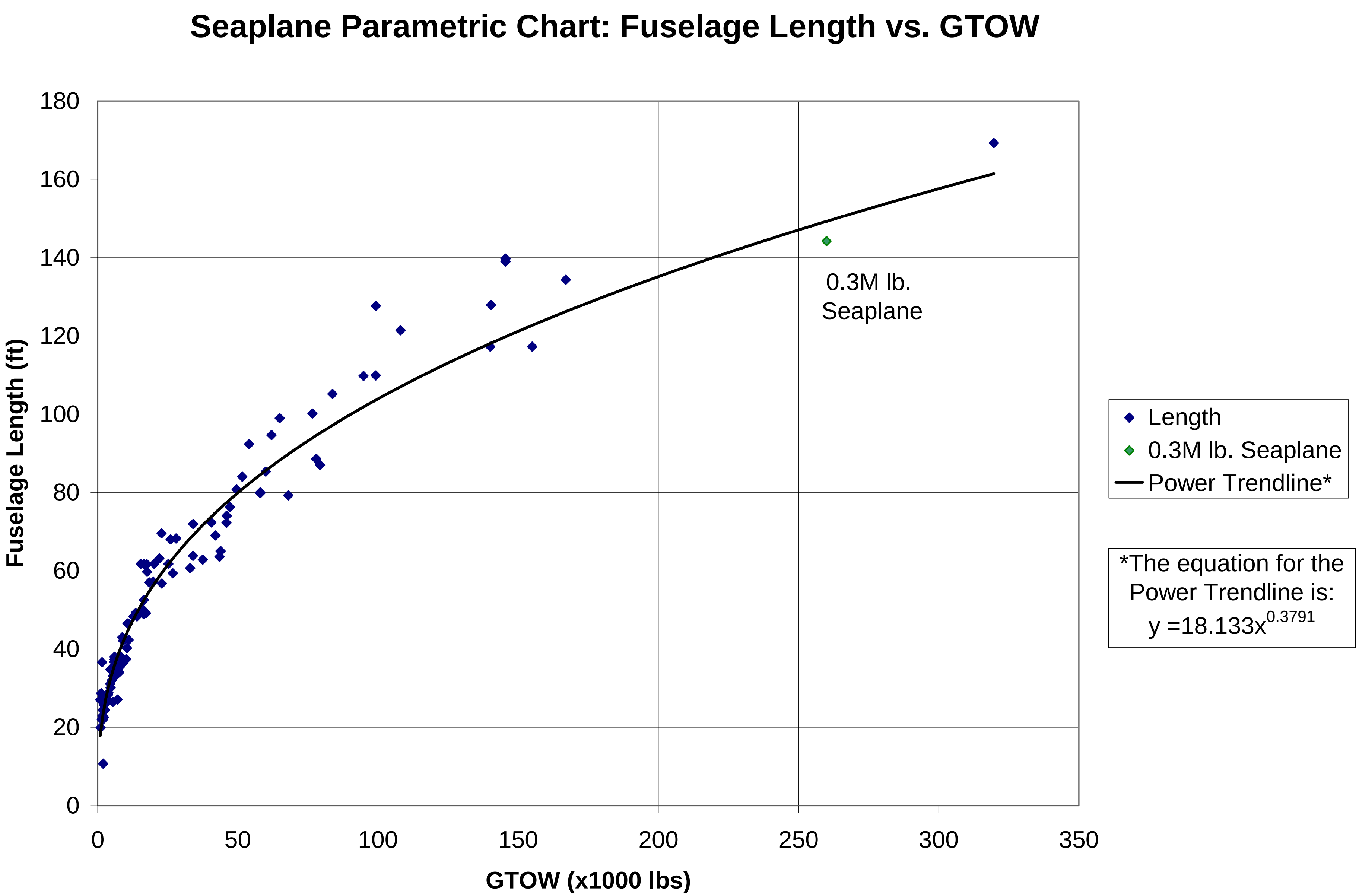



**Figure 8. Seaplane parametric chart – Fuselage length vs. GTOW with 0.3 M lb. seaplane.**

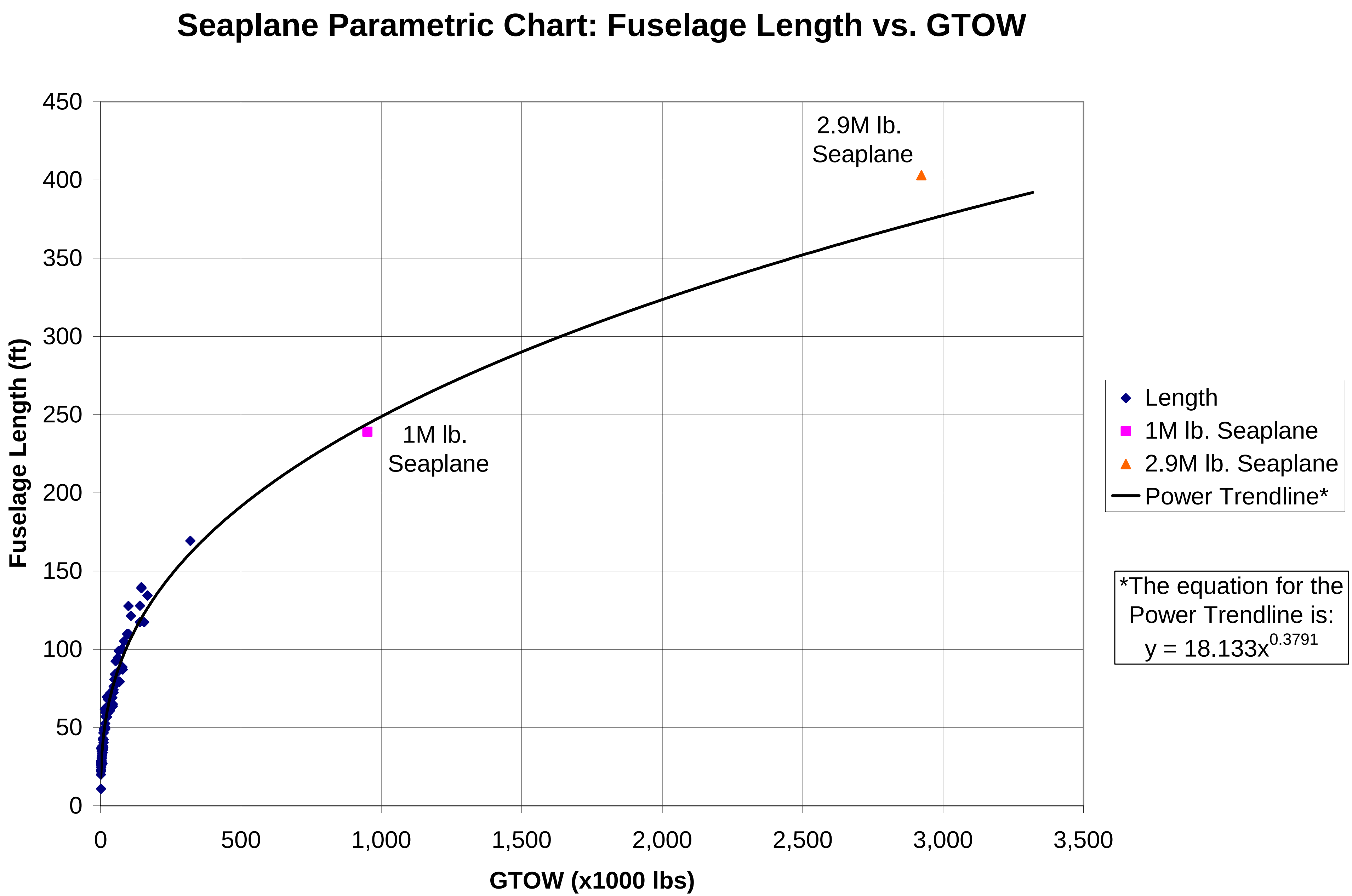



**Figure 9. Seaplane parametric chart – Fuselage length vs. GTOW with BFS-1.0 M lb, 2.9 M lb. seaplanes.**

### 2.1.4 Empty Weight vs. Gross Take-off Weight

Figures 10 and 11 were created from information supplied by Naval Surface Warfare Center Carderock Division, West Bethesda, MD. The three seaplanes designed by the Advanced Airborne Systems Design branch fell below the parametric curve of the supplied data. The data shows a linear ratio of empty weight to GTOW of 0.6. The AASD design data for the BFS 1.0 M lb. and the BFS 2.9 M lb. seaplanes showed a ratio of empty weight over GTOW equal to 0.49. The empty weight to gross take-off weight ratio for the 0.3 M lb. seaplane was 0.53. Figure 10 shows the 0.3 M lb. seaplane plotted in relation to the seaplane data. Figure 11 shows the BFS-1.0 M and 2.9 M lb. seaplanes plotted in relation to the seaplane data.

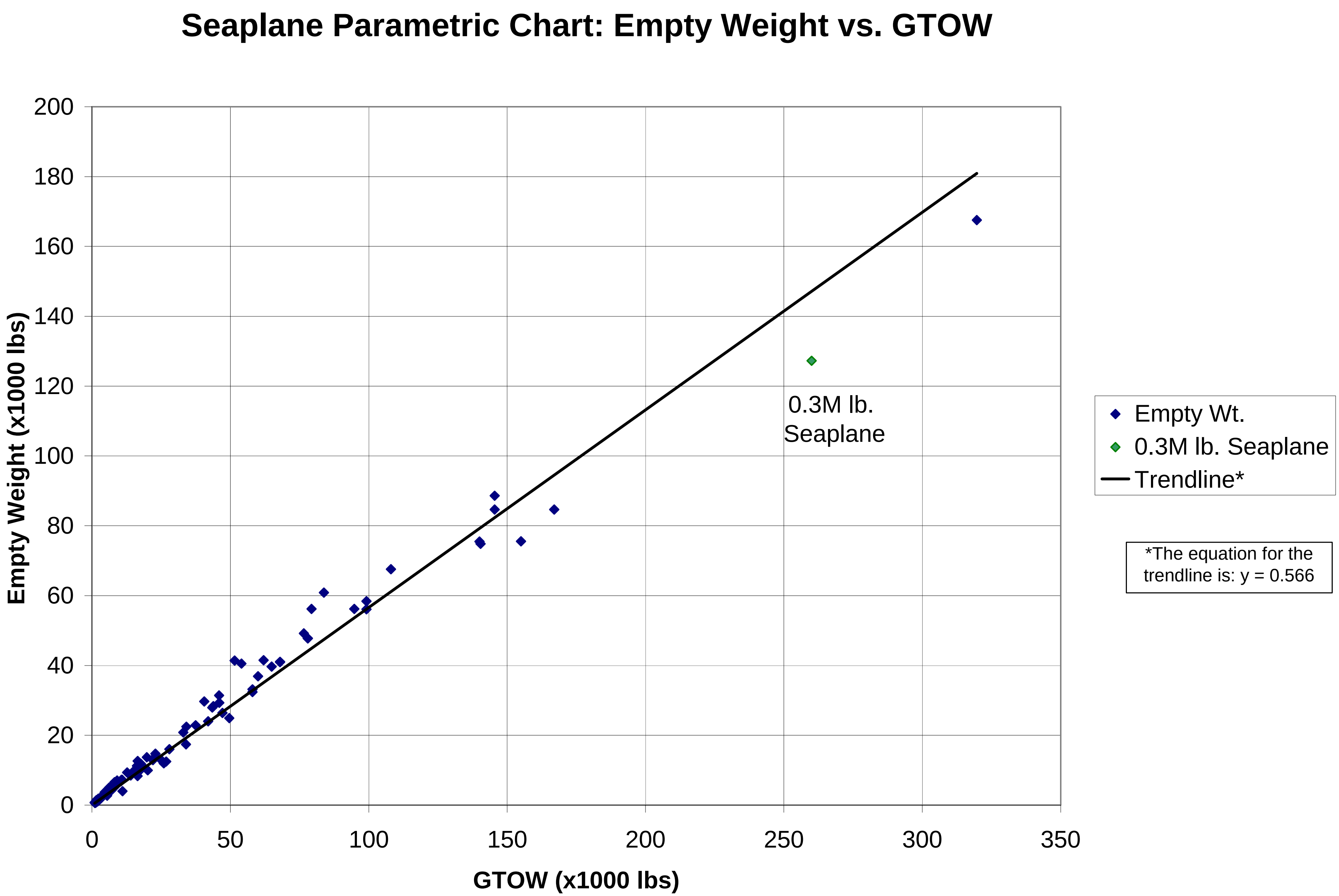



**Figure 10. Seaplane parametric chart – Empty weight vs. GTOW with 0.3 M lb. seaplane.**

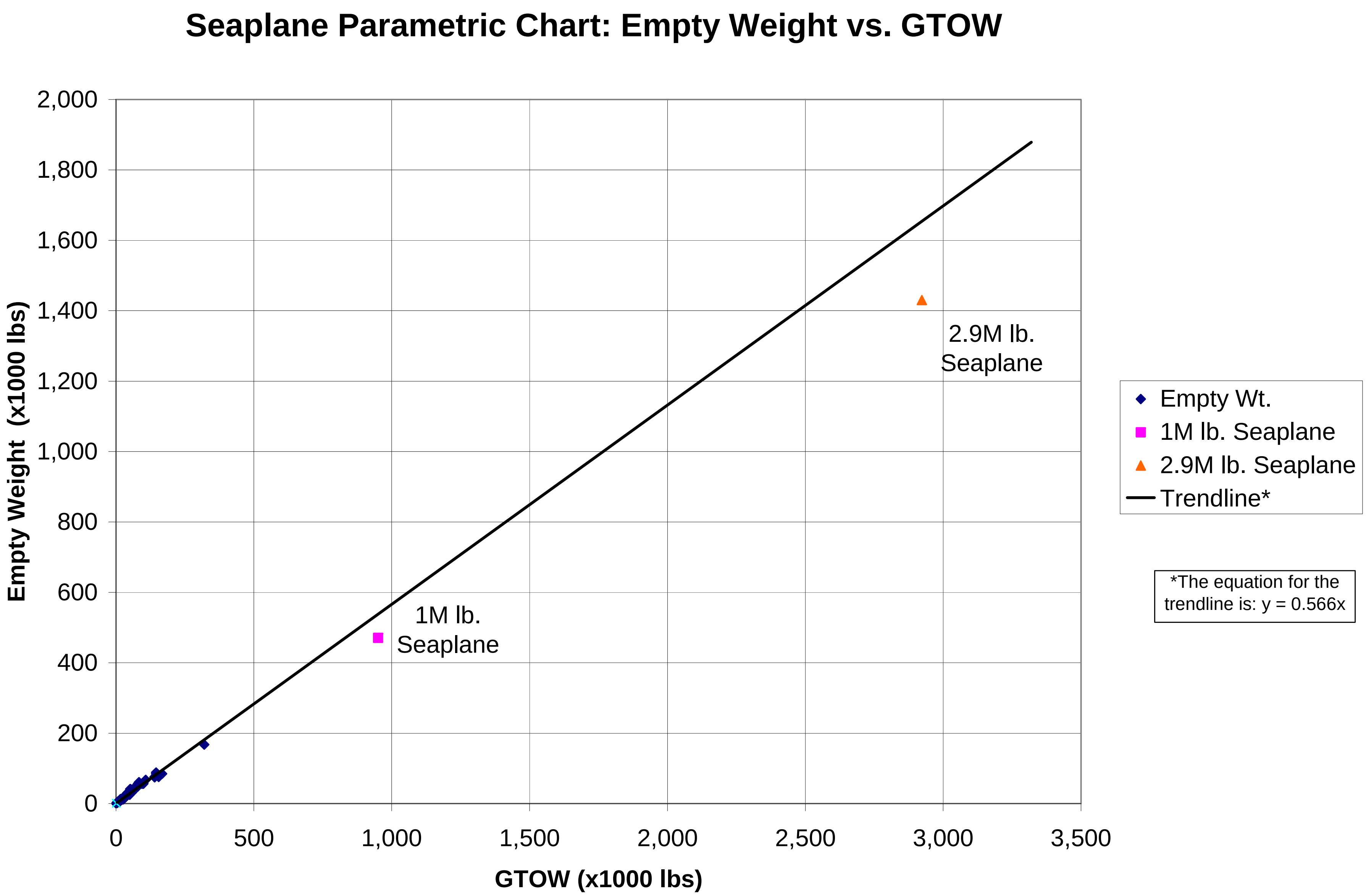



**Figure 11. Seaplane parametric chart – Empty weight vs. GTOW with BFS-1.0 M lb., 2.9 M lb. seaplanes.**

### 2.1.5 Regression Line List of Seaplane Weights versus Wetted Areas (Source: Jan Roskam, Airplane Preliminary Design Part I: Preliminary Sizing of Airplanes 1997)

The BFS 2.9 M lb., BFS 1.0 M lb., and the 0.3 M lb. seaplane designs are very close to the trend line of the other aircraft, as seen in Figure 12. Above the GTOW of 1,000,000 lbs., the GTOW increases linearly, where the weight increases faster than the wetted area. This can be shown by the following:

Starting at 500,000 lbs the weight increases faster than the wetted area.

At a weight of 500,000 lbs. the wetted area is 30,000 $ft^2$. This corresponds to a weight per wetted area ratio of 16.6 $lb/ft^2$.

At a weight of 1,000,000 lbs., the wetted area is 48,000 $ft^2$. This corresponds to a weight per wetted area ratio of 20.8 $lb/ft^2$.

At a weight of 3,500,000 lbs., the wetted area is 100,000 $ft^2$. This corresponds to a weight per wetted area ratio of 35 $lb/ft^2$.

This shows that the weight is increasing faster than the wetted area. On a logarithm plot the exponential curve trend appears as a straight line.

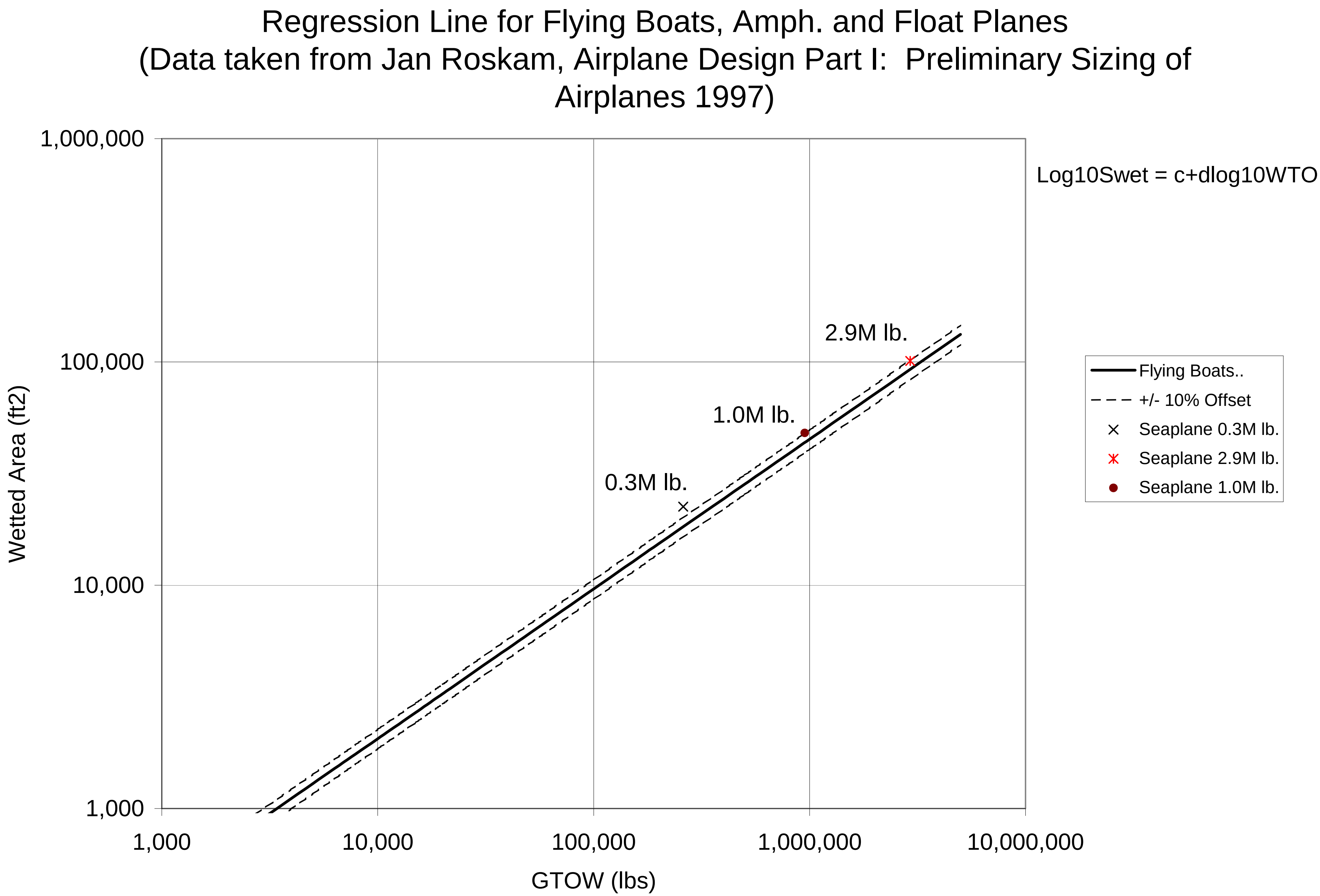



**Figure 12. Regression Line for Flying Boats, Amphibians, and Float Planes with the 3 seaplanes plotted. Source: Roskam, Jan "Airplane Design Part I: Preliminary Sizing of Airplanes 1997**

## 2.2 BASE CASE LIFT CAPACITY

The base case is design data for the BFS-0.3 M lb., BFS-1.0 M lb., and BFS-2.9 M lb. seaplane for the unimproved design condition. This is the benchmark for comparison against the improvements of the seaplane design to be shown later in this report. All range calculations are for a ferry mission for ease of comparison.

### 2.2.1 Aerodynamic Analysis

The aerodynamics analysis of the two early designs, Battleforce Seaplane (BFS) 1.0 M lb. and 2.9 M lb. was performed using standard textbook aerodynamic equations, standard aircraft characteristics (SAC) charts, and Air Force Stability and Control Data Compendium (DATCOM) equations. In the 1993-1994 timeframe the speed of the aircraft was approximately M = 0.82. Therefore, the calculations included Reynolds numbers effects for drag in the area of compressibility. All characteristics were calculated, including sweepback angle, etc. The details of the aerodynamics were recorded in the following reports, “BFS 1.0 M lb. Seaplane Design and Performance” [3] and “BFS 2.9 M lb. Design and Performance” [4]

A lower fidelity aerodynamic analysis was performed on the 0.3 M lb. Seaplane due to time constraints and a lower speed requirement.

The process used to calculate the 0.3 M lb. seaplane was simplified due to time constraints and the reduced flight velocity as compared to the first two aircraft.

The drag analysis of the seaplane hull and step was performed using NACA reports, (see section 2.3.1.1).

### 2.2.2 Weight Analysis

The weights analysis for the 1.0 M lb. and the 2.9 M lb. seaplanes were originally performed without computer codes. In 1994 at NAWC, Warminster [3,4] the analysis was performed as follows:

1. Compile a database including transport and seaplane information, wing loading, power to weight ratios, etc.
2. Compile configuration data from Jane’s All the World’s Aircraft, Standard Aircraft Characteristics Charts, Martin P6M data from Defense Technical Information Center, Office of Naval Research, David Taylor Model Basin, etc.
3. Generate parametric charts, including wetted area versus maximum take-off weight of large aircraft.
4. Compile manuals from manufacturers detailing methods used for estimating weights. An example method would be to use the bending moments, shear forces, and other forces acting on the wing through semi-empirical charts to determine the wing weight.
5. Calculate the wing loading and bounded it within a lower range to ensure low landing speeds necessary for sea worthiness.
6. Iteration until convergence.

#### 2.2.2.1 Aircraft Sizing Spreadsheet

The Aircraft Sizing Spreadsheet was built from the Raymer empirical equations for conceptual aircraft design. Simple performance equations were used to determine the fuel fraction required to perform a given mission based on the most important design characteristics of the aircraft shape, engines and atmosphere. The various weight fractions along with payload and crew weights and an estimate of the GTOW are used to calculate the actual GTOW of the conceptual airplane. The initial estimated GTOW is then iteratively recalculated until it matches the calculated GTOW for a given design and mission.

For this study, the weights portion of the spreadsheet was calibrated to each base case seaplane. Engine installation factors were applied to get the correct specific fuel consumption at the cruise altitude. The lift to drag ratio (L/D) was corrected from conceptual performance data to obtain the correct fuel fractions.

### 2.2.3 Generalities of Flying Boat Design

To understand how to improve a design, a great deal of reference information must be accumulated. A flying boat is basically an aircraft with a boat hull. This fuselage must be designed to perform double duty. The hull has to have buoyancy for itself as a boat, and it also must be large enough for the added weight of the wings and engines. This buoyant hull has to be fairly deep to support its weight and to keep the fuselage with the windows, doors etc. out of the water.

The characteristics of a seaplane with propellers and a seaplane with jet engines are very different. With propellers the engines must be mounted high to keep the propellers out of the water spray. This means more weighty structure and more drag. With jet engines, the height necessary to keep the engine out of the water spray is minimized; therefore the fuselage need not be as deep, thus saving weight and drag. The seaplane using jet engines is much more aerodynamically and structurally efficient.

Figure 13 on page 25 shows a flying boat in planing attitude, and Figure 14 on page 26 shows flying forces on take-off [1]. These figures are referenced during the following discussion on seaplane operation during take-off.

The hull of a flying boat and the pontoon of a floatplane are based on the planing hull concept. The bottom is fairly flat allowing the aircraft to skim/plane on the top of the water at low hydrodynamic resistance and high speed. A step breaks the suction on the afterbody. This is the principle behind the hydroplaning speed boat. It is possible to have a hydroplaning boat without a step, but that requires significantly more power.

In order to understand how to make improvements in seaplane design, it is helpful to review the mechanics of take-off and hull design aspects.

Seaplane Take-off

The method in which a seaplane takes off illustrates the function of the seaplane hull design. The take-off can be divided into four hydrodynamically significant phases as discussed below:

1. Low Speed Displacement Regime
As power is applied, the hull is essentially a displacement vessel moving at low speed and low trim angle. The forebody and afterbody support the weight of the airplane by buoyant forces, which are dependent on the immersed volume of each section. The hydrodynamic resistance is composed of friction forces on the wetted surfaces of the hull, form drag, and wave making drag. Figure 15 parts a) and b) illustrates the situation.

2. Hump Speed Regime
The hump speed regime, Figure 15 part c) is the second phase of take-off. This occurs at approximately 30-40% of the take-off speed and is associated with the transition between the displacement and the planing speed regimes. The trim is determined by the step and afterbody design. There is flow separation from the forebody step and the afterbody intersecting at mid length and reduces its immersed volume. The associated reduction in afterbody hydrodynamic load and bow down moment enables the forebody force (applied forward of the LCG) to increase the hull trim and thus increase its drag.

At this point the aerodynamic unloading is about 15% of the gross weight, at a take-off speed of 35%, $\frac{V}{V_G} = 35\%$.

3. Planing Speed Regime
The planing speed regime exists between 40% and 80% of the take-off speed. The forebody wake has separated from the afterbody. The hydrodynamic load is now between 80% and 30% of the gross weight and is supported by the forebody. The forebody load decreases with increasing speed, and the hull trim angle decreases to maintain equilibrium between the forebody hydrodynamic load and the weight on the water.

Since the forebody is in a planing regime, the chines and step must be shaped in order to assure separation of flow from the forebody bottom. In this speed regime, the hull behavior is primarily determined by the after half of the forebody geometry. It is essential that the buttock lines in this regime be straight and convex surfaces be avoided. In this regime, the aerodynamic forces on the horizontal stabilizer must be sufficient to provide manual trim control of the aircraft so that an optimum take-off trim track can be selected.

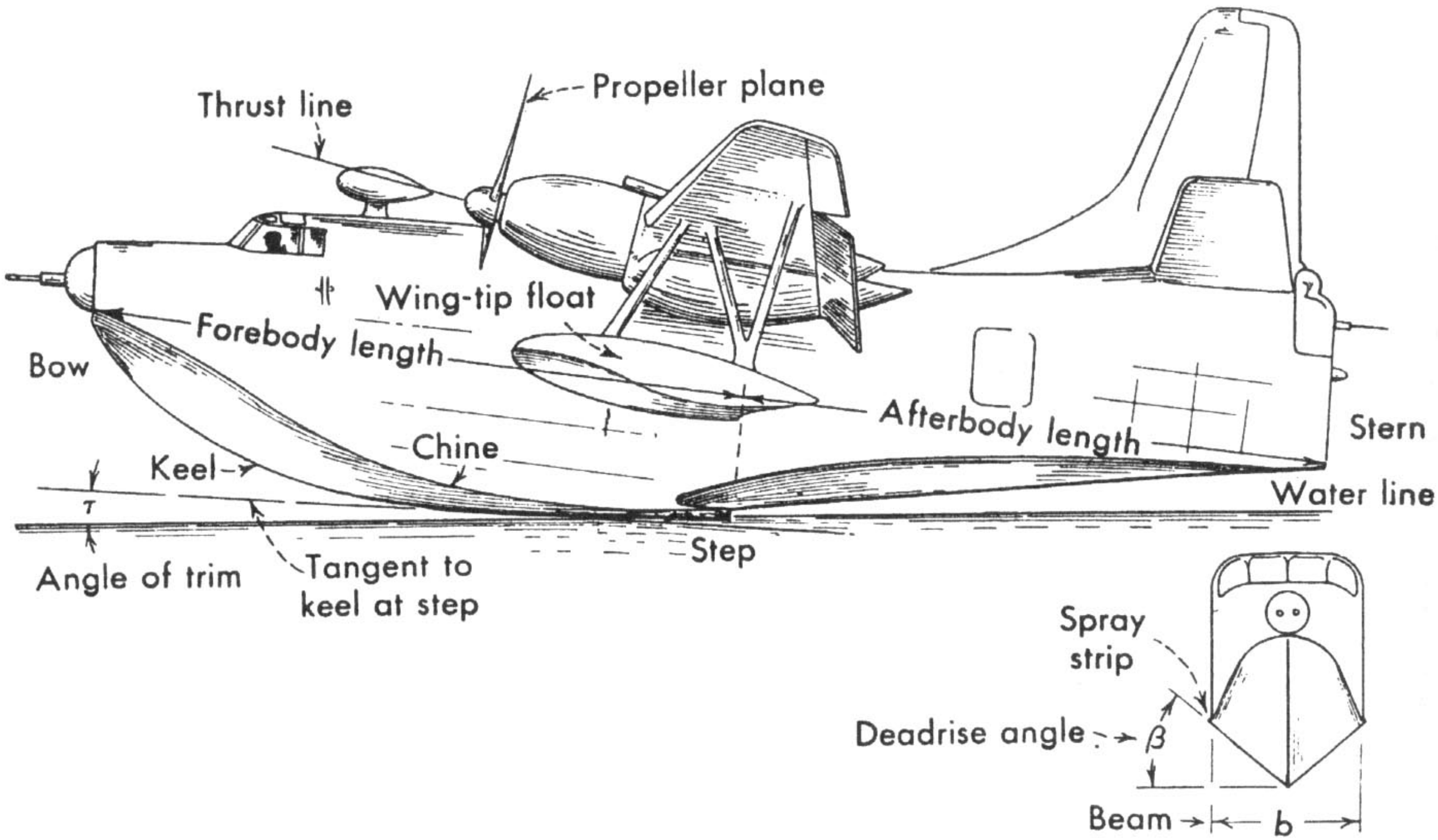



**Figure 13. A flying boat in planing attitude.**

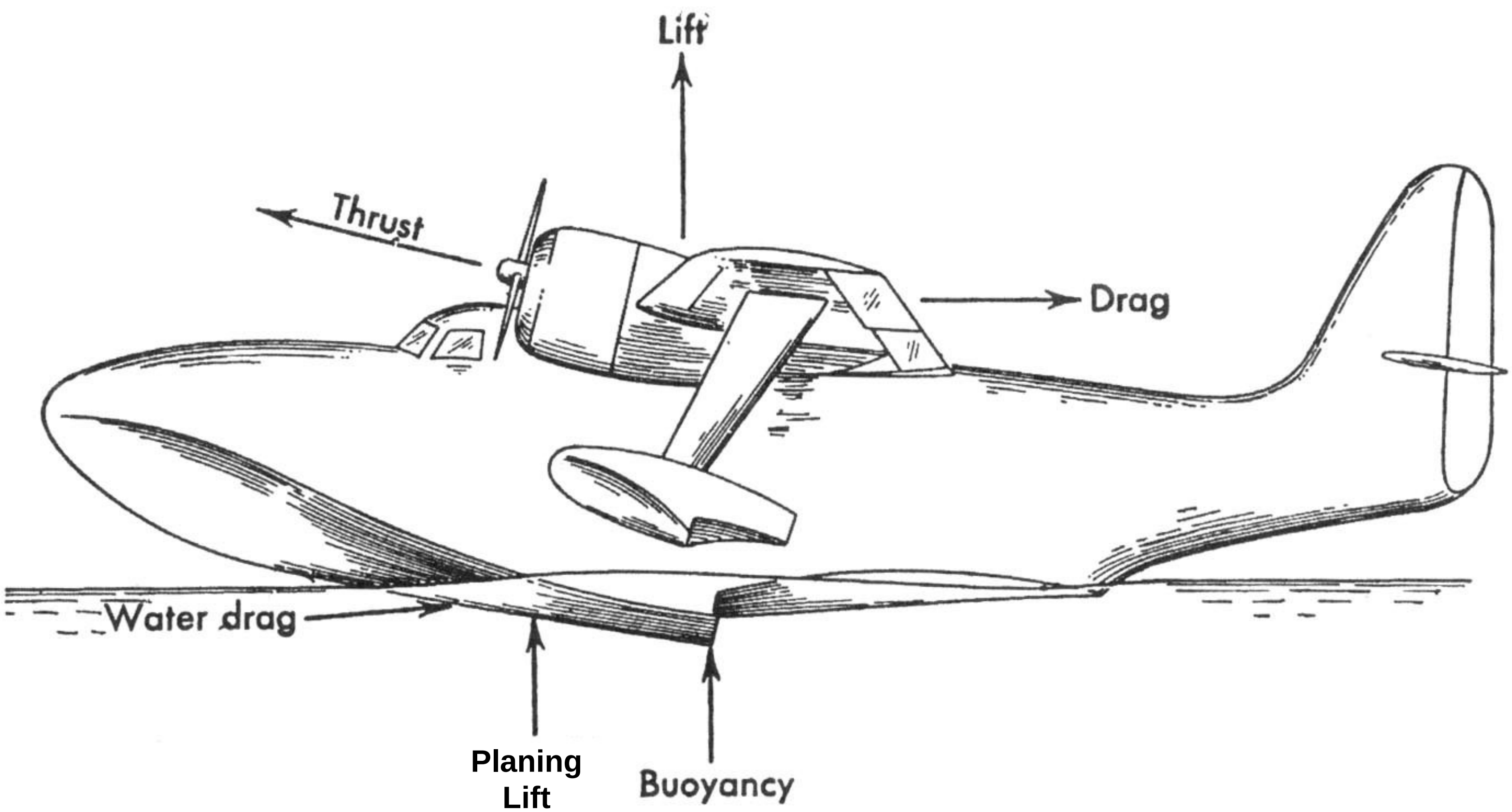
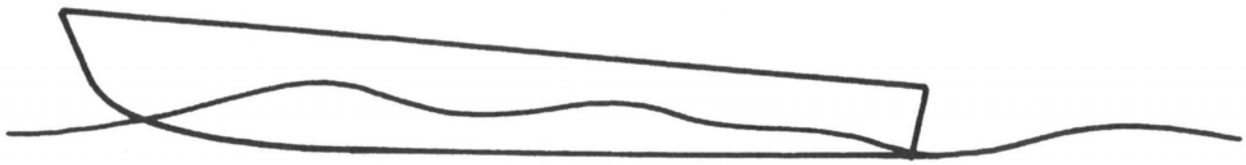
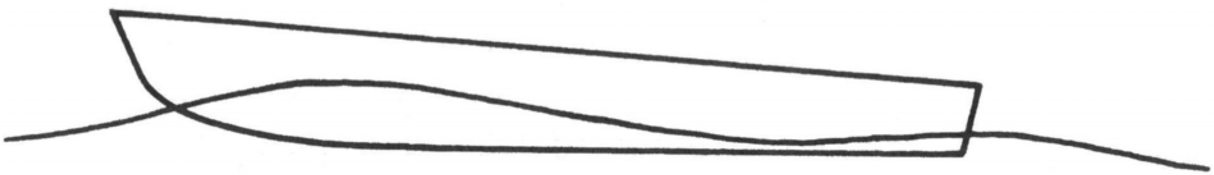


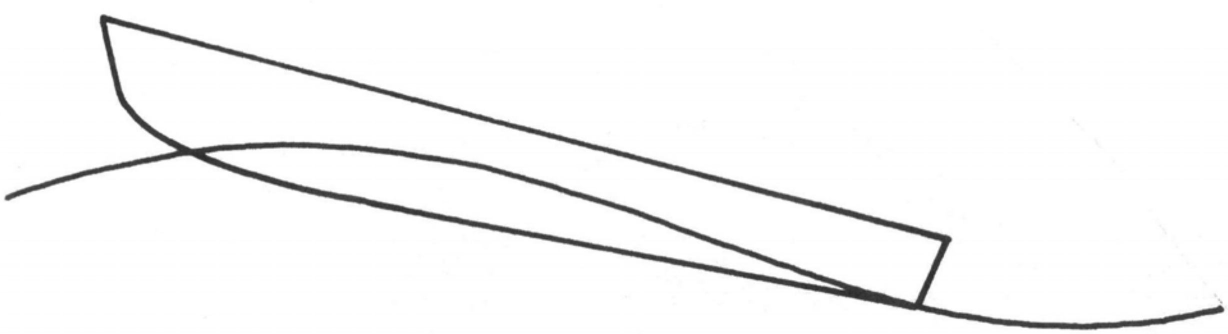

**Figure 14. Flying forces on take-off.**



a. Wave-making at low speed.



b. Critical condition in which second wave is pushing forward on the stern.



c. Higher speed, at the 'hump' where drag is a maximum, with the hull climbing its own bow wave.

**Figure 15. Low speed and hump displacement regimes.**

4. Take-off Speed Regime
The take-off speed regime is between 80% and 100% of the take-off speed. The pilot adjusts the horizontal stabilizer to increase the aircraft trim angle to obtain optimum wing lift at take-off. The hydrodynamic forces are concentrated on a small triangular area just forward of the step. The afterbody configuration and the after length of the forebody have a direct influence on the hull behavior in this regime.

## Notes on Seaplane Design

The following was taken from “A Summary of Hydrodynamic Technology Related to Large Seaplanes” [5].

> “Increases in length to beam ratio result in reduction in aerodynamic drag.” “…there is 20% reduction in hull drag coefficient associated with an increase in length to beam ratio from 6.0 to 12.”
>
> “Increasing the length to beam ratio from 6 to 12 has resulted in nearly an 8% reduction in structural weight of hull for equal performance”

### Forebody Design Notes

Most successful seaplane designs have a forebody length that varies between 58% to 60% of the total length of the hull.

### Afterbody Design Notes

The function of the afterbody is to provide adequate aft buoyancy and level trim when the seaplane is at rest. In the hump speed region, the afterbody limits the hump trim angle and consequently limits the hump drag. In this speed range it is essential for a designer to provide an afterbody configuration, which is clear of the water surface and forebody wake.

### Deadrise – Afterbody

The afterbody deadrise immediately aft of the step should be larger than the forebody deadrise in order to provide a clear opening at the chines to the atmosphere and this assures ventilation of the step and a clean separation of flow form the forebody bottom.

### Deadrise –Forebody

For otherwise identical initial landing condition – the maximum impact acceleration is approximately proportional to $\cot(\beta)$, (deadrise angle, $\beta$). Thus, the impact force on a region of zero deadrise hull is infinite and approaches a value of zero when the deadrise is 90°.

The steady state planing efficiency (expressed as lift to drag ratio) increases with decreasing deadrise and has a maximum value at zero deadrise. As an acceptable compromise between low impact loads and high planing efficiency,

typical seaplane forebodies have approximately 20° deadrise at the step. The forebody deadrise increases toward the bow in order to reduce bow impact forces and resistance when operating in waves.

Hull Design Parameters used on BFS 1.0 M lb. Seaplane

The three seaplane hulls were designed using design configuration relationships found in Sauvitsky, et al. [5] and configuration parameters of the following aircraft:

- Beriev A-40
- Martin XP6M-1
- Hughes Flying Boat
- NAWC-AD-WAR Seaplane

For the BFS 1.0 M lb. Seaplane

Length of Forebody – Lf = 1525 in.
Length of Afterbody– La = 1210 in.
Length of Hull – L = 228 ft. = 2736 in.
Beam– B = 21 ft. = 252 in.

| | Sources |
|---|---|
| L/b = 10.8 | Sauvitsky [5] – 6.0 to 12 |
| Lf = Length of Forebody = 1525 in.<br>Lf/L = 1525 in. / 2740 in. = 0.556 | Sauvitsky [5] –<br>53% to 60% of L |
| La/L = 1210 in. /2740 in. = 0.44 | Sauvitsky [5] – 40% to 50% of L |

From the previous explanation, the operation and function of the seaplane hull is an integral part of the seaplane design. The hull design uses a hydroplane design method to obtain high speed with the least power by causing a major portion of the hull to lift out of the water for low water drag on the step, but the seaplane, in contrast to a hydroplane boat, has to achieve a high angle of attack to take-off. This behavior is similar to a land plane. With a seaplane, the afterbody (sternpost) bottom has to angle away from the step so that it allows rotation. Once it rotates on the step the afterbody of the hull must be clear of the water. This is why a hull needs a sternpost angle of approximately 7°. Alternatively, a stepless hull requires a large amount of power or blowing to break the suction in order to liftoff. This power addition and/or extra equipment will add additional weight to the seaplane.

### 2.2.4 0.3 M lb. Seaplane Base Case

Background

This design is the 0.3 M lb. seaplane design for NSWC, Carderock Md. “Conceptual Design for Battleforce Seaplane Concept 3” [7]. The report includes a 3-view design and analysis. The weights analysis method is in Section 2.2.2 Weight Analysis and 2.2.2.1 Aircraft Sizing Spreadsheet.

#### 2.2.4.1 Specification

SEAPLANE - 0.3 M lbs.
Type: 60,000 lb. Payload Airlift Seaplane

CONSTRUCTION: ALL ALUMINUM

WINGS: AIRFOIL, T/C=12% MAX T/C $\geq$ 0.4C
TRIPLE SLOTTED FOLWER FLAPS, SLATS OUTBOARD,
KRUEGER FLAPS INBOARD, (TRIMMED CL MAX - 2.8)

FUSELAGE: CONVENTIONAL SEMIMONOCOUQE, FAIL SAFE
STRUCTURE OF SKIN, STRINGERS, & RING FRAMES

TAILS:

| | |
|---|---|
| HORIZONTAL TAIL AIRFOIL - | NACA 0009 |
| VERTICAL TAIL AIRFOIL - | NACA 0009 |

POWERPLANT:

SIX ALLISON AE2100 TURBOPROP ENGINES EACH RATED AT 4,591 SHP

ACOMODATION: 0.3M LB. SEAPLANE

| | | |
|---|---|---|
| PERSONNEL | = | 180 Troops |
| or 8FTx8FTx20FT CARGO CONTAINERS | = | 4 MAX |

DIMENSIONS EXTERNAL:

| | |
|---|---|
| WING SPAN | = 162.8 FT. |
| WING SWEEP | = 0 DEGREES |
| WING ASPECT RATIO | = 10.08 |
| DIHEDRAL | = 0 DEGREE |
| LENGTH OVERALL | = 155 FT. 1 IN. |
| LENGTH OF HULL | = 144 FT. 2 IN. |
| BEAM | = 25 FT. 9 IN. |
| HULL LENGTH / BEAM | = 11.3 |
| FOREBODY LENGTH / HULL LENGTH | = 0.49 |

### 2.2.4.1 Specification cont.

<u>FLOOR AREA:</u>

| | | |
|---|---|---|
| CARGO FLOOR | = | 760 $FT.^2$ |

<u>VOLUME</u>:

| | | |
|---|---|---|
| PRESSURIZED SECTION | = | 20,030 $FT.^3$ |

<u>AREAS</u>:

| | | |
|---|---|---|
| WING | = | 2,650 $FT.^2$ |
| HORIZONTAL TAIL | = | 620 $FT.^2$ |
| VERTICAL TAIL | = | 567 $FT.^2$ |

<u>WEIGTS AND LOADINGS</u>

| | | |
|---|---|---|
| GROSS TAKEOFF WEIGHT | = | 260,003 LBS. |
| EMPTY WEIGHT | = | 127,244 LBS. |
| DESIGN PAYLOAD | = | 60,000 LBS. |
| WING LOADING (MAX) | = | 99.3 $LBS./FT.^2$ |
| POWER LOADING T/W (MAX) | = | 0.280 |
| MAX FUEL LOAD CAPACITY | = | 71,759 LBS. |

## 2.2.4.1 Specification cont.

PERFORMANCE AT 20,000 FEET

(ESTIMATED AT MAX T.O. WIEGHT EXCEPT WHERE INDICATED)

| | | | | |
|---|---|---|---|---|
| MAXIMUM CRUISE SPEED | = | 380.77 | KTS. | (.62M) |
| FUEL FLOW | = | 1,671 | LBS./HR. | |
| TSFC | = | 0.50 | 1/HR. | |
| BEST RANGE SPEED | = | 356.32 | KTS. | (0.58M) |
| FUEL FLOW | = | 1,642 | LBS./HR. | |
| TSFC | = | 0.468 | 1/HR. | |
| L/D | = | 13.95 | | |
| BEST ENDURANCE SPEED | = | 278 | KTS. | (0.453M) |
| FUEL FLOW | = | 1,555 | LBS./HR. | |
| TSFC | = | 0.384 | 1/HR. | |
| L/D | = | 15.89 | | |
| RANGE WITH 60,000 LBS. PAYLOAD AT BEST RANGE SPEED OF 356 KTS. WITH 1 HR. RESERVE | = | 2,812 | NM. | |
| FERRY RANGE AT BEST RANGE SPEED OF 356 KTS. WITH 1 HR. RESERVE | = | 6,575 | NM. | |

SEA LEVEL PERFORMANCE

| | | | |
|---|---|---|---|
| STALL SPEED | = | 97 | KTS. |

### 2.2.4.2 Three View

0.3 M lb. Seaplane

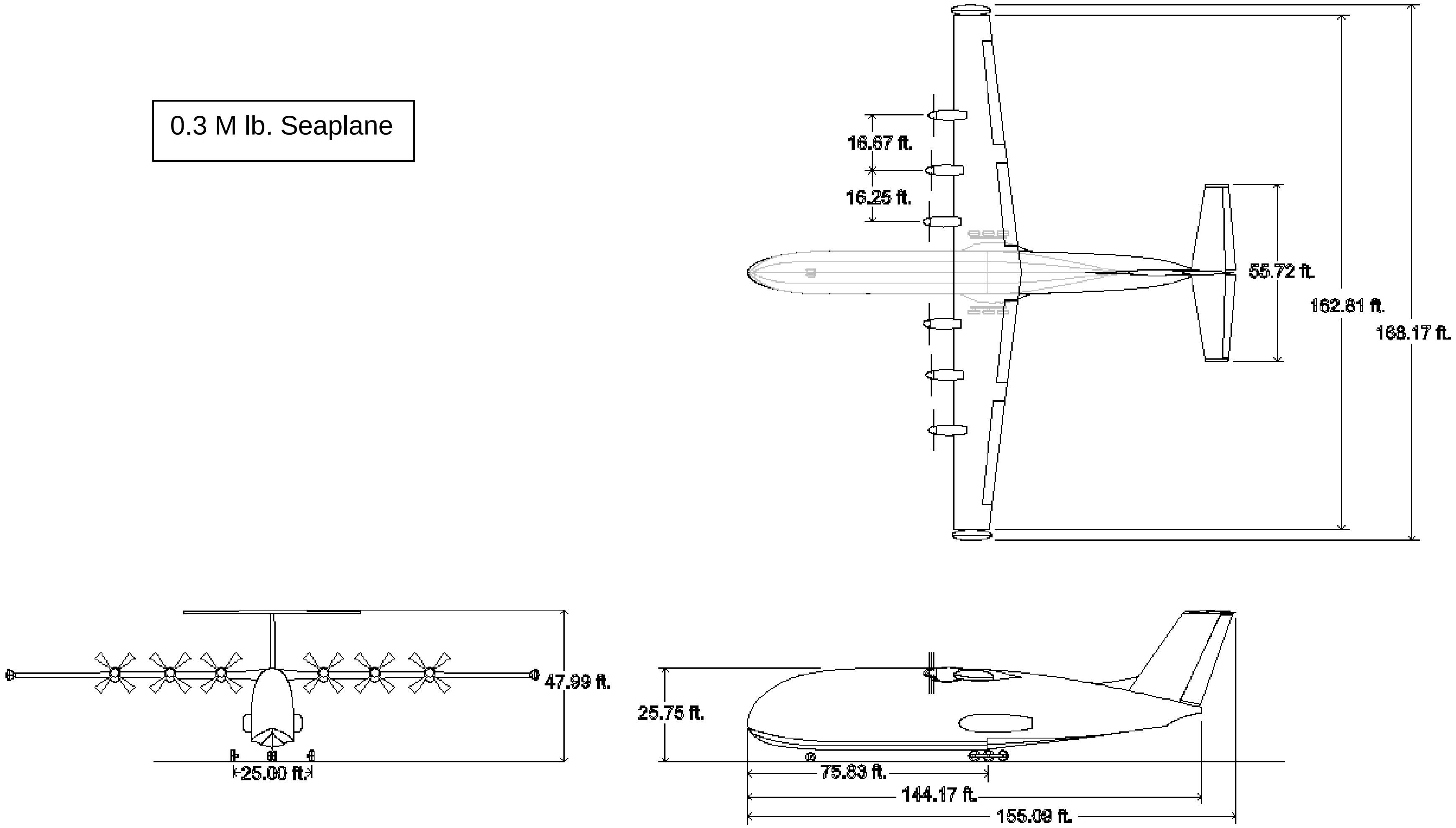



**Figure 16. 0.3 M lb Seaplane Three View**

### 2.2.4.3 Weight Breakdown

The weight derived for the 0.3 M lb. seaplane was developed using Raymer empirical weight equations. The weights for the base seaplane were developed using calibration factors based on a C130 model. Corrections were made for the increased weight associated with a seaplane hull. Figure 17 shows the weight breakdown for the 0.3 M lb. seaplane base case.

**0.3 M lb. Seaplane - Base Case Weight Breakdown**

| | |
|---|---|
| Structure Group | 77,271 lbs. |
| Propulsion Group | 24,004 lbs. |
| Equipment Group | 25,969 lbs. |
| Empty Weight | 127,244 lbs. |
| Gross Take-off Weight | 260,003 lbs. |

**Figure 17. Base Case – 0.3 M lb. Seaplane Weight Breakdown**

### 2.2.4.4 Drag Breakdown

Drag is broken into two main categories, parasite drag and induced drag. The parasite drag portion for the 0.3 M lb. seaplane was estimated using parametric relationships between wetted area, equivalent flat plate area, and the equivalent skin friction [6], see Figure 19. The equivalent flat plate area for the BFS-0.3 M lb. was 60 $ft^2$. Using the relations and the expression: $C_{Do} = f / S$, where f is the equivalent flat plate area and S is the wing reference area. The induced drag was developed from the following relationship $C_{Di} = C_L^2/(\pi Ae)$. A detailed discussion of the drag breakdown method is explained in section 2.2.1. The results are shown below in Figure 18.

**0.3M Lb. Seaplane @ 20,000 ft.-STEP**

| Mach | CDi | CDo | $CD_{total}$ |
|---|---|---|---|
| 0.2 | 0.5431 | 0.023 | 0.5661 |
| 0.3 | 0.1073 | 0.023 | 0.1303 |
| 0.4 | 0.0339 | 0.023 | 0.0569 |
| 0.5 | 0.0139 | 0.023 | 0.0369 |
| 0.6 | 0.0067 | 0.023 | 0.0297 |
| 0.7 | 0.0036 | 0.023 | 0.0266 |
| 0.8 | 0.0021 | 0.023 | 0.0251 |

**Figure 18. Base Case – 0.3 M lb. Seaplane Drag Breakdown**

## Effect of Equivalent Skin Friction on Parasite and Wetted Areas
## Source: Jan Roskam "Airplane Design Part I: Preliminary Sizing of Airplanes" c2003 pg. 120

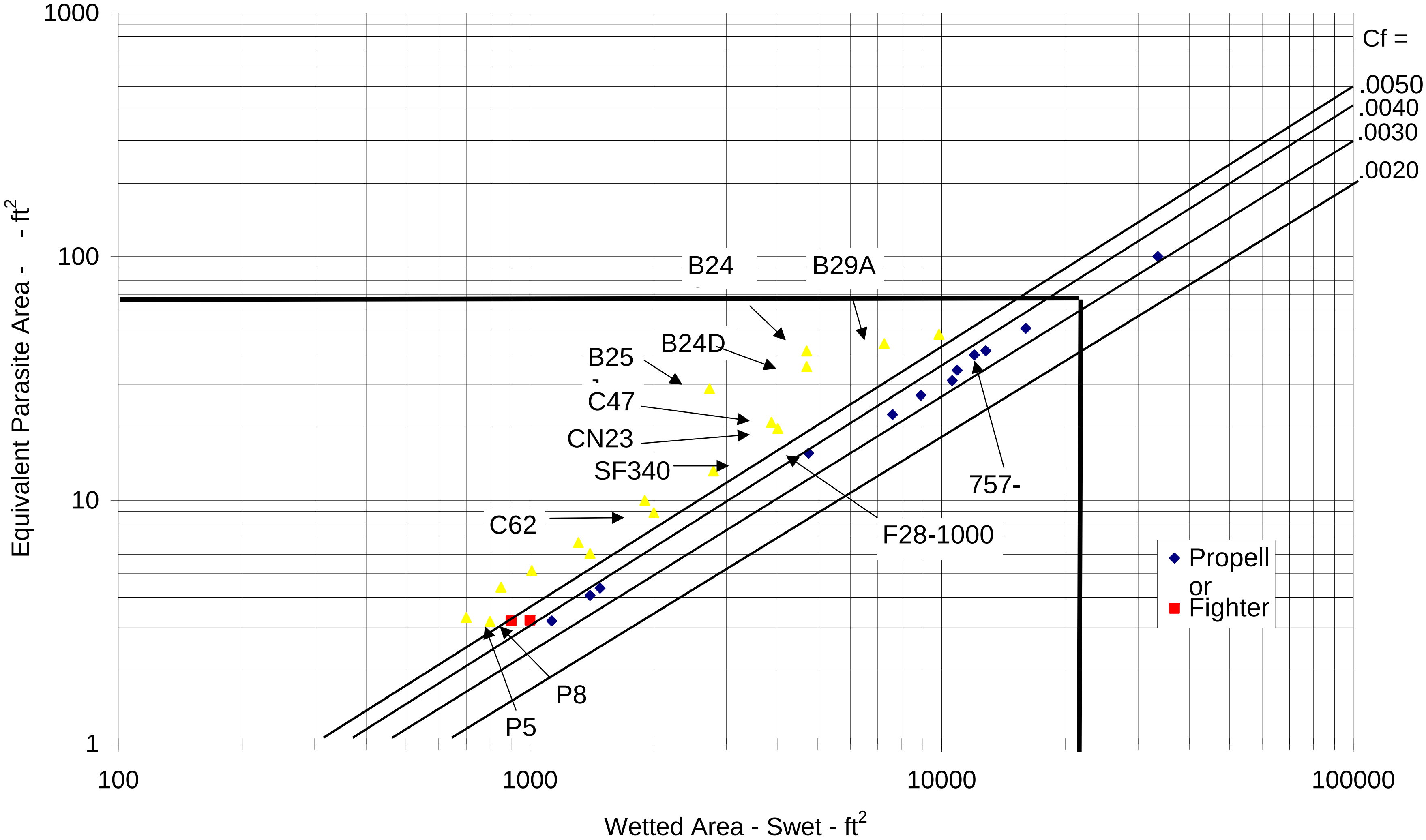



**Figure 19. Equivalent flat plate area for BFS-0.3 M lb. parasite drag estimation**

#### 2.2.4.5 Speed, Performance, Thrust Required versus Thrust Available at Sea Level

The details are in "Conceptual Design for Battleforce Seaplane Concept 3" [7]. The drag analysis equations and results are shown in Figure 20. The resulting performance curves for sea level are shown in Figure 21.

The intersection of the thrust available and thrust required is the maximum cruise speed. The maximum speed for the 0.3 M lb. seaplane at sea level is M=0.486.

The maximum range cruise velocity is found at the tangent point from a line drawn from the origin to the thrust required curve. The maximum range for the 0.3 M lb. seaplane at sea level is Mach 0.38.

The maximum difference between the thrust required and thrust available gives the excess thrust, which will give the maximum rate of climb at sea level.

**DRAG TABLE: 0.3 M Lb. Seaplane @ Sea Level**

| Mach | V | ρ | q | 1/q | CL | $CL^2$ | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | lbm/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | $(W/(S*q))^2$ | $CL^2$/(pi*AR*e) | | CDo+CDi | CDtot*q*S |
| 0.1 | 111.64 | 0.002377 | 14.81 | 0.06751178 | 6.6239 | 43.8757 | 1.8359 | 0.023 | 1.8589 | 72965 |
| 0.2 | 223.28 | 0.002377 | 59.25 | 0.01687794 | 1.6560 | 2.7422 | 0.1147 | 0.023 | 0.1377 | 21627 |
| 0.3 | 334.92 | 0.002377 | 133.31 | 0.00750131 | 0.7360 | 0.5417 | 0.0227 | 0.023 | 0.0457 | 16132 |
| 0.4 | 446.56 | 0.002377 | 237.00 | 0.00421949 | 0.4140 | 0.1714 | 0.0072 | 0.023 | 0.0302 | 18949 |
| 0.5 | 558.2 | 0.002377 | 370.31 | 0.00270047 | 0.2650 | 0.0702 | 0.0029 | 0.023 | 0.0259 | 25453 |
| 0.6 | 669.84 | 0.002377 | 533.24 | 0.00187533 | 0.1840 | 0.0339 | 0.0014 | 0.023 | 0.0244 | 34503 |
| 0.7 | 781.48 | 0.002377 | 725.80 | 0.00137779 | 0.1352 | 0.0183 | 0.0008 | 0.023 | 0.0238 | 45708 |
| 0.8 | 893.12 | 0.002377 | 947.98 | 0.00105487 | 0.1035 | 0.0107 | 0.0004 | 0.023 | 0.0234 | 58906 |

$$Thrust\_Required = CD_{TOTAL} \cdot q \cdot S$$

$$CD_{TOTAL} = Cd_o + Cd_i$$

$$Cd_i = \frac{C_L^{\ 2}}{(\pi \cdot AR \cdot E)}$$

$$C_L = \frac{W}{(S \cdot q)}$$

**Figure 20. Base Case – 0.3 M lb. Seaplane drag calculations at sea level.**

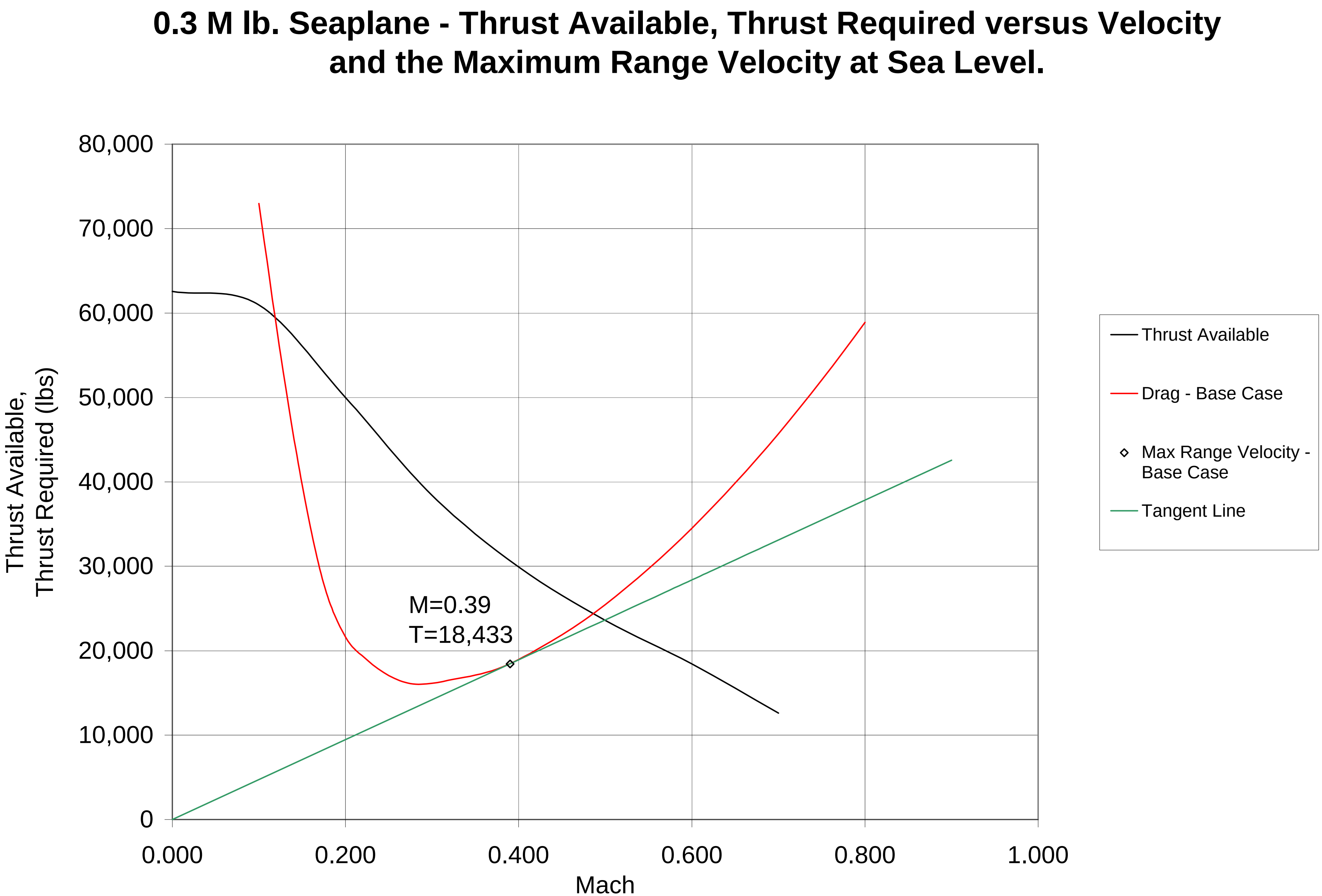



**Figure 21.  Base Case – 0.3 M lb. Seaplane thrust available, thrust required vs. velocity and max range velocity at sea level.**

### 2.2.4.6 Speed, Performance, Thrust Required versus Thrust Available at 20,000 ft.

The drag analysis equations and results are shown in Figure 22.
The resulting performance curves for the cruise altitude of 20,000 ft. are shown in Figure 23.

The intersection of the thrust available and thrust required is the maximum cruise speed. The maximum speed for the 0.3 M lb. seaplane at an altitude of 20,000 ft. is M=0.619.

The maximum range cruise velocity is found at the tangent point of a line drawn from the origin to the thrust required curve. The maximum range cruise velocity for the 0.3 M lb. seaplane at 20,000 ft. is M=0.58.

The cruise lift to drag ratio (L/D) point for this study was taken as the maximum range point, M = 0.58. The cruise L/D for maximum range was found to be 13.95.

The maximum difference between the thrust required and thrust available gives the excess thrust, which will give the maximum rate of climb at 20,000 ft.

**DRAG TABLE: 0.3 M Lb. Seaplane @ 20,000 ft.**

| Mach | V | ρ | q | 1/q | CL | $CL^2$ | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | lbm/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | $(W/(S*q))^2$ | $CL^2$/(pi*AR*e) | | CDo+CDi | CDtot*q*S |
| 0.2 | 207.38 | 0.00126643 | 27.23 | 0.03672096 | 3.6029 | 12.9805 | 0.5431 | 0.023 | 0.5661 | 40856 |
| 0.3 | 311.07 | 0.00126643 | 61.27 | 0.01632043 | 1.6013 | 2.5641 | 0.1073 | 0.023 | 0.1303 | 21155 |
| 0.4 | 414.76 | 0.00126643 | 108.93 | 0.00918024 | 0.9007 | 0.8113 | 0.0339 | 0.023 | 0.0569 | 16438 |
| 0.5 | 518.45 | 0.00126643 | 170.20 | 0.00587535 | 0.5765 | 0.3323 | 0.0139 | 0.023 | 0.0369 | 16645 |
| 0.6 | 622.14 | 0.00126643 | 245.09 | 0.00408011 | 0.4003 | 0.1603 | 0.0067 | 0.023 | 0.0297 | 19293 |
| 0.7 | 725.83 | 0.00126643 | 333.60 | 0.00299763 | 0.2941 | 0.0865 | 0.0036 | 0.023 | 0.0266 | 23532 |
| 0.8 | 829.52 | 0.00126643 | 435.72 | 0.00229506 | 0.2252 | 0.0507 | 0.0021 | 0.023 | 0.0251 | 29007 |

$$Thrust\_Required = CD_{TOTAL} \cdot q \cdot S$$

$$CD_{TOTAL} = Cd_o + Cd_i$$

$$Cd_i = \frac{C_L{}^2}{(\pi \cdot AR \cdot E)}$$

$$C_L = \frac{W}{(S \cdot q)}$$

**Figure 22. Base Case – 0.3 M lb. Seaplane drag calculations for cruise altitude of 20,000 ft.**

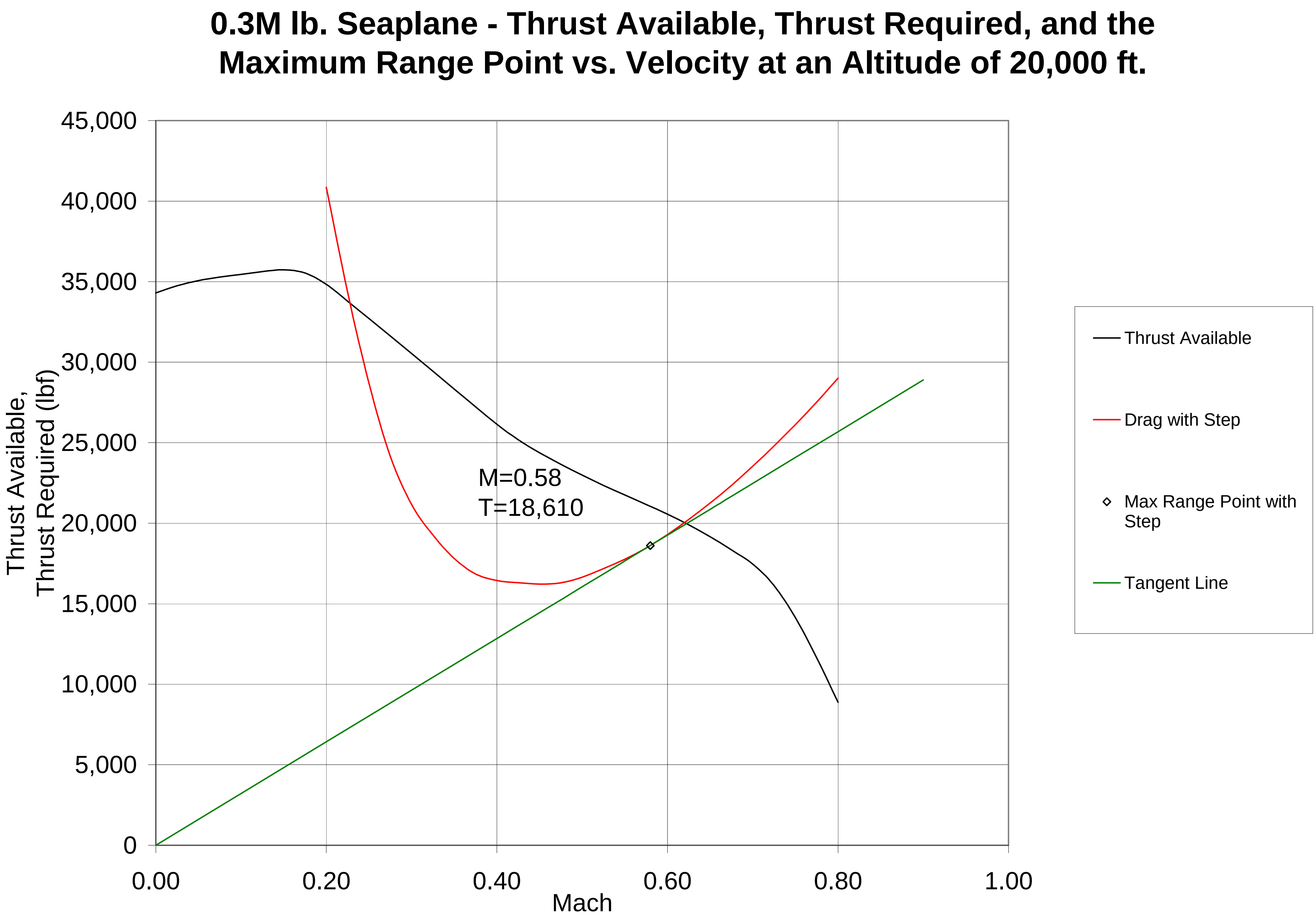



**Figure 23. Base Case – 0.3 M lb. Seaplane thrust available, thrust required vs. velocity and max range velocity for cruise altitude of 20,000 ft.**

### 2.2.4.7 Range vs. Payload

Range is calculated using the Brequet equation: $R_{cr} = \left(\frac{V}{C}\right) \cdot \left(\frac{L}{D}\right) \cdot \ln\left(\frac{W_{i-1}}{W_i}\right)$. From the previous section, the velocity at the maximum range and the lift to drag ratio are known. The specific fuel consumption is known through performance curves taken from the engine manufacturer. The change in weight from the beginning segment to the end segment is found from the calibrated Raymer based weight sizing spreadsheet. The results of the Brequet range equation calculations are shown in Figure 24. The tabulated results show that the maximum range for a ferry mission is 6,576 nm. A graphic plot of the results is given in Figure 25.

**0.3M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure - Base Case**

| **Ferry Mission** | | | Definitions |
|---|---|---|---|
| GTOW | 260,003 | lbf. | GTOW - Gross Takeoff Weight |
| Empty | 127,244 | lbf. | Empty - Empty weight |
| Useful | 132,759 | lbf. | Useful - The difference between GTOW and Empty |
| Crew | 1,000 | lbf. | |
| 5% Reserve | 6,274 | lbf. | |
| V | 356.32 | kts. | V - Velocity in knots (M=0.58) at 20,000 ft. |
| C | 0.468 | lbf./hr/lbf. | C - Total Specific Fuel Consumption |
| CD | 0.0307 | lbf. | |
| CL | 0.4277 | lbf. | |
| L/D | 13.95 | | |
| $W_{i-1}$ | 253,971 | lbf. | $W_{i-1}$ - Initial weight for segment. |
| $W_i$ | 136,781 | lbf. | $W_i$ - Final weight for segment. |

**Brequet Range Equation**

$R_{cr}$ = (V/C)*(L/D)*ln($W_{i-1}$/$W_i$)

$R_{cr}$ = 6575.6 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 131,759 |
| 1,336 | 90,000 |
| 2,812 | 60,000 |
| 4,526 | 30,000 |
| 6,576 | 0 |

| | | | | |
|---|---|---|---|---|
| Altitude | 20,000 ft | a | 1036.9 | FT/SEC |
| | | M | 0.58 | |
| | | V=M*a | 601.402 | FT/SEC |
| C | 0.4679 | V | 356.32 | KTS |

**Figure 24. Base Case – 0.3 M lb. Seaplane Range vs. Payload Calculations**

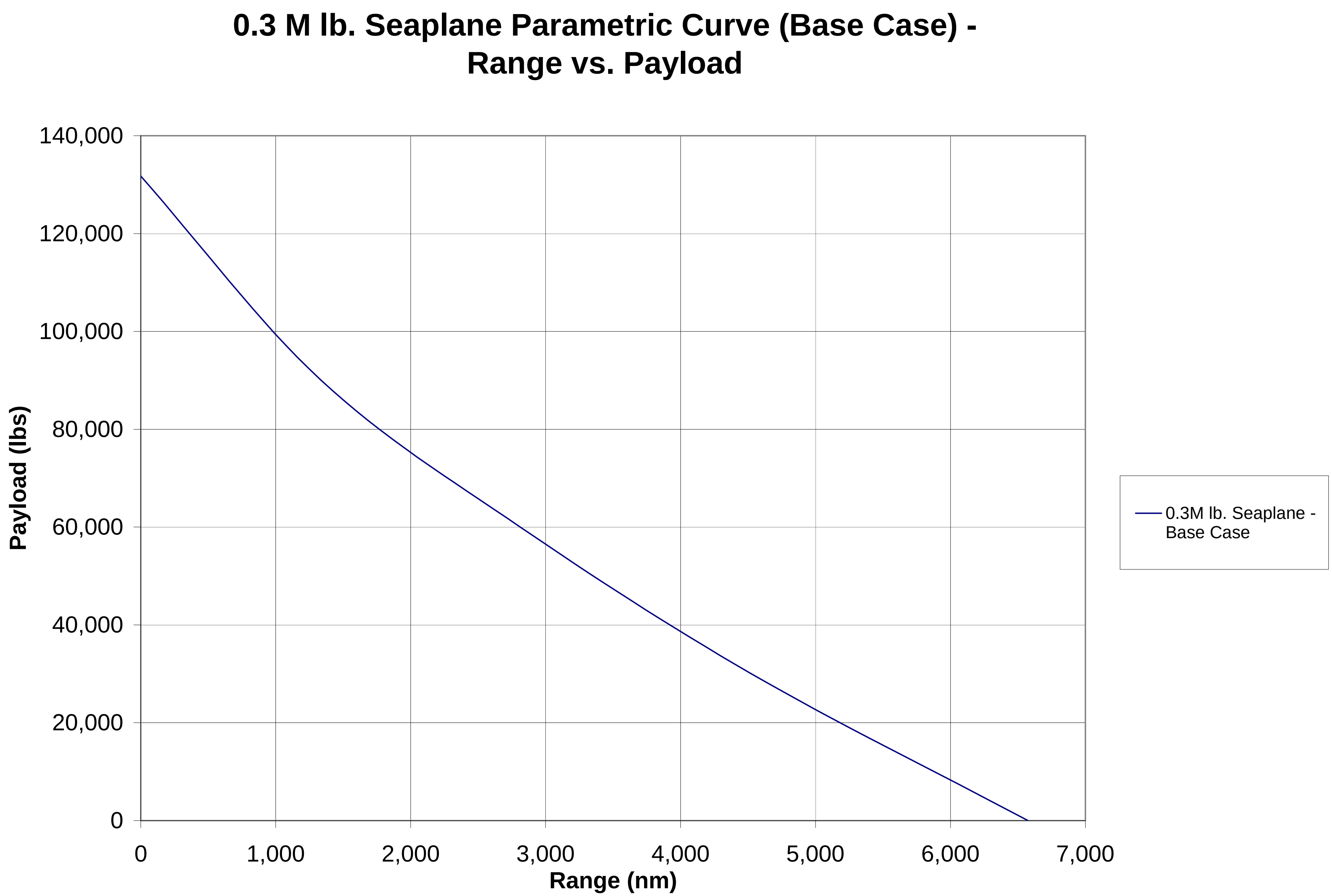



**Figure 25. Base Case – 0.3 M lb. Seaplane Range vs. Payload.**

## 2.2.5 1.0 M LB. SEAPLANE BASE CASE

### 2.2.5.1 Specification

BATTLE FORCE SEAPLANE - 1.0 M lbs.
Type: 360,000 lb. Payload Airlift Seaplane

CONSTRUCTION: ALL ALUMINUM

WINGS: AIRFOIL, T/C=12% MAX T/C ≥ 0.4C
TRIPLE SLOTTED FOLWER FLAPS, SLATS OUTBOARD,
KRUEGER FLAPS INBOARD, (TRIMMED CL MAX - 2.8)

FUSELAGE: CONVENTIONAL SEMIMONOCOUQE, FAIL SAFE
STRUCTURE OF SKIN, STRINGERS, & RING FRAMES

TAILS:

HORIZONTAL TAIL AIRFOIL - NACA 0009
VERTICAL TAIL AIRFOIL - NACA 0009

POWERPLANT:

FOUR PRATT & WHITNEY 4088 TURBOFAN ENGINES EACH RATED AT 90300 LB. TAKE-OFF THRUST

ACOMODATION: BFS 1.0M LB. SEAPLANE

| | | |
|---|---|---|
| Upper Deck Forward | = | 201 Troops |
| Upper Deck Aft | = | 166 Troops |
| Lower Deck - w/o Ramp | = | 445 Troops |
| or M60A3 Main Battle Tanks | = | 3 Max |

DIMENSIONS EXTERNAL:

| | | |
|---|---|---|
| WING SPAN | = | 315 FT. |
| WING SWEEP | = | 28 DEGREES |
| WING ASPECT RATIO | = | 8.74 |
| DIHEDRAL | = | 0 DEGREE |
| LENGTH OVERALL | = | 270 FT. 9 IN. |
| LENGTH OF HULL | = | 228 FT. 4 IN. |
| BEAM | = | 21 FT. 6 IN. |
| HULL LENGTH / BEAM | = | 10.6 |
| FOREBODY LENGTH / HULL LENGTH | = | 0.556 |

## 2.2.5.1 Specification cont.

DIMENSIONS INTERNAL:

| | | |
|---|---|---|
| UPPER DECK FOREWARD ( L X W X H ) | = | 79 FT. X 17 FT. X 8 FT. |
| UPPER DECK AFT ( L X W X H ) | = | 65 FT. X 17 FT. X 8 FT. |
| LOWER CARGO DECK ( L X W X H ) | = | 158 FT. X 18 FT. X 13 FT. |

FLOOR AREA:

| | | |
|---|---|---|
| UPPER DECK FORWARD | = | 1,311 $FT.^2$ |
| UPPER DECK AFT | = | 1,079 $FT.^2$ |
| LOWER DECK, WITHOUT RAMP | = | 2,896 $FT.^2$ |

VOLUME:

| | | |
|---|---|---|
| UPPER DECK FORWARD | = | 10,360 $FT.^3$ |
| UPPER DECK AFT | = | 8,524 $FT.^3$ |
| LOWER DECK, WITHOUT RAMP | = | 38,528 $FT.^3$ |

AREAS:

| | | |
|---|---|---|
| WING | = | 11,362 $FT.^2$ |
| HORIZONTAL TAIL | = | 1,876 $FT.^2$ |
| VERTICAL TAIL | = | 1,970 $FT.^2$ |

STABILITY COEFFICIENTS:

| | | |
|---|---|---|
| HORIZONTAL TAIL VOLUME COEF. | = | 0.526 |
| VERTICAL TAIL VOLUME COEF. | = | 0.053 |

WEIGTS AND LOADINGS

| | |
|---|---|
| GROSS TAKEOFF WEIGHT | 950,600 LBS. |
| EMPTY WEIGHT | 470,432 LBS. |
| DESIGN PAYLOAD | 360,000 LBS. |
| WING LOADING (MAX) | 83.7 $LBS./FT.^2$ |
| POWER LOADING T/W (MAX) | 0.379 |
| MAX FUEL LOAD CAPACITY | 478,368 LBS. |

## 2.2.5.1 Specification cont.

PERFORMANCE AT 30,000 FEET

(ESTIMATED AT MAX T.O. WIEGHT EXCEPT WHERE INDICATED)

| | | | |
|---|---|---|---|
| MAXIMUM CRUISE SPEED | = | 484 KTS. | (0.82M) |
| FUEL FLOW | = | 11,769 LBS./HR. | |
| TSFC | = | 0.576 1/HR. | |
| BEST RANGE SPEED | = | 416 KTS. | (0.705M) |
| FUEL FLOW | = | 10,964 LBS./HR. | |
| TSFC | = | 0.539 1/HR. | |
| L/D | = | 18.99 | |
| BEST ENDURANCE SPEED | = | 484 KTS. | (0.822M) |
| FUEL FLOW | = | 11,769 LBS./HR. | |
| TSFC | = | 0.56115 1/HR. | |
| L/D | = | 21.60 | |
| RANGE WITH 360,000 LBS. PAYLOAD AT BEST RANGE SPEED OF 416 KTS. WITH 1 HR. RESERVE | = | 1,220 NM. | |
| FERRY RANGE AT BEST RANGE SPEED OF 416 KTS. WITH 1 HR. RESERVE | = | 8,929 NM. | |
| RANGE w/225,000 LBS. PAYLOAD (2 TANKS + 100 TROOPS) | = | 3,652 NM. | |

SEA LEVEL PERFORMANCE

| | | |
|---|---|---|
| TAKE-OFF DISTANCE GROUND RUN | = | 3,245 FT. |
| STALL SPEED | = | 94 KTS. |
| TOUCH DOWN SPEED | = | 103 FT. |

## 2.2.5.2 Three View

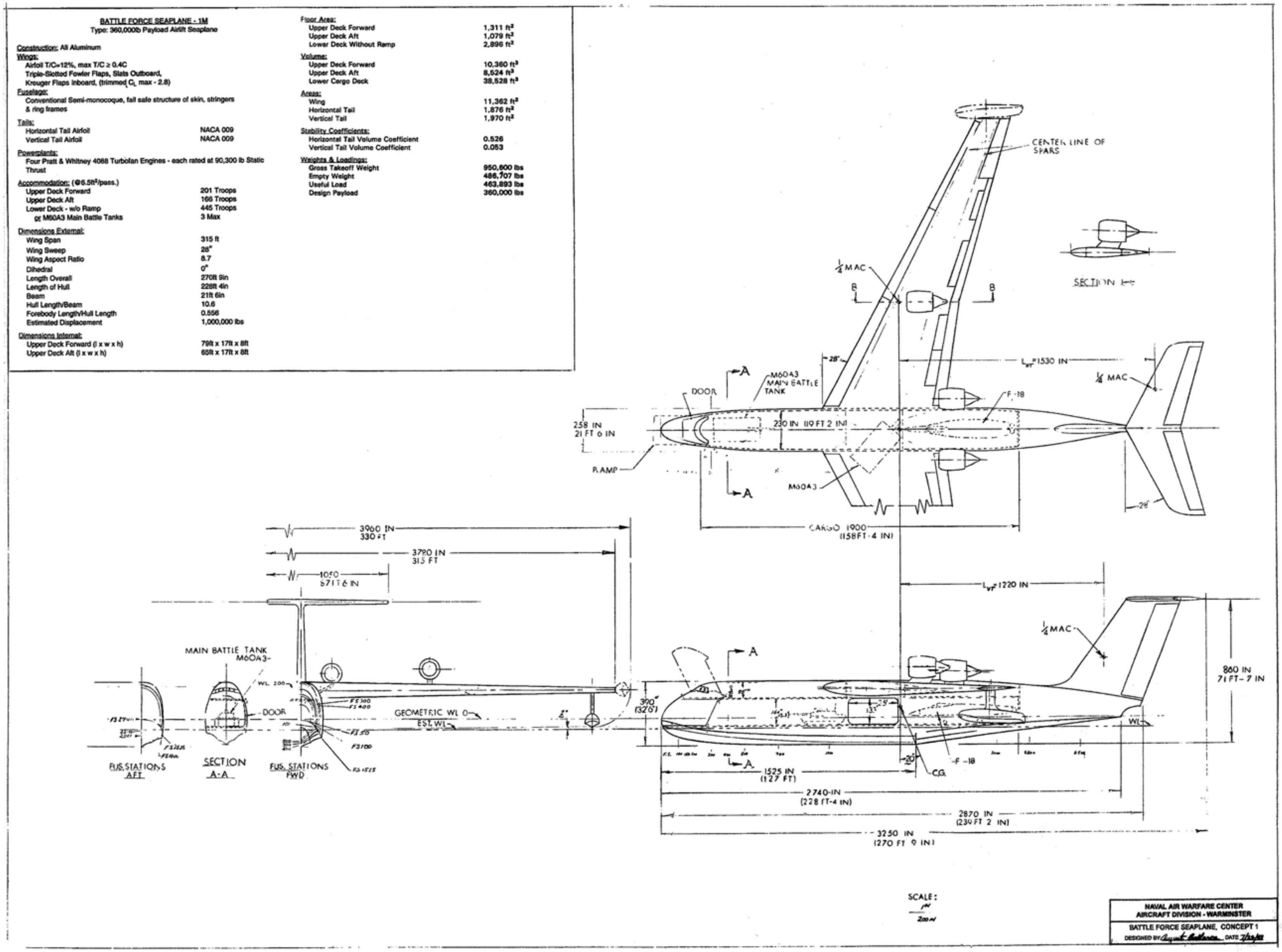



**Figure 26. 1.0 M lb. Seaplane Three View**

### 2.2.5.3 Weight Breakdown

The weight analysis methods that were used are explained in section 2.2.2. The first analysis was completed at the Naval Warfare Center, Warminster in 1994 [3]. The analysis was performed using parametric equations developed from industry and conceptual design groups. For this report, it was reproduced using the Raymer based empirical and parametric equations. The results of this analysis are shown below in Figure 27.

**1.0M lb. Seaplane - Base Case Weight Breakdown**

| | |
|---|---|
| Structure Group | 325,332 lbs. |
| Propulsion Group | 91,695 lbs. |
| Equipment Group | 53,405 lbs. |
| Empty Weight | 470,432 lbs. |
| Gross Take-off Weight | 950,600 lbs. |

**Figure 27. Base Case – 1.0 M lb. Seaplane weight breakdown.**

### 2.2.5.4 Drag Breakdown

The basic drag analysis was performed as explained in section 2.2.1. The analysis was developed using the USAF Stability and Control Data Compendium (DATCOM) information and other aerodynamic texts. The drag of the step is shown in section 2.3.1.1. The parasitic breakdown is shown below in Figure 28.

**DRAG BREAKDOWN - COMPONENT METHOD**
**1.0 M lb. Seaplane**

| | M = 0.2 | M = 0.4 | M = 0.6 | M = 0.7 | M = 0.8 | M = 0.9 |
|---|---|---|---|---|---|---|
| **Component** | **Cdo** | **Cdo** | **Cdo** | **Cdo** | **Cdo** | **Cdo** |
| **Body** | 0.00320 | 0.00290 | 0.00277 | 0.00277 | 0.00277 | 0.00277 |
| **Step** | 0.00090 | 0.00090 | 0.00090 | 0.00090 | 0.00090 | 0.00090 |
| **V. Tail** | 0.00121 | 0.00111 | 0.00108 | 0.00114 | 0.00143 | 0.00710 |
| **H. Tail** | 0.00131 | 0.00120 | 0.00117 | 0.00124 | 0.00153 | 0.00670 |
| **Wing** | 0.00590 | 0.00543 | 0.00530 | 0.00560 | 0.00730 | 0.03830 |
| **Pontoons** | 0.00023 | 0.00019 | 0.00017 | 0.00017 | 0.00017 | 0.00017 |
| **Engines** | 0.00140 | 0.00123 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| **Engine Mts.** | 0.00020 | 0.00017 | 0.00015 | 0.00015 | 0.00015 | 0.00015 |
| **Cdo** | 0.01435 | 0.01313 | 0.01269 | 0.01312 | 0.01540 | 0.05724 |
| **Protuberances** | X 1.1 | X 1.1 | X 1.1 | X 1.1 | X 1.1 | X 1.1 |
| **Total Cdo** | 0.01579 | 0.01444 | 0.01396 | 0.01443 | 0.01694 | 0.06296 |

**Figure 28. Base Case – 1.0 M lb. Seaplane Parasite Drag Breakdown**

### 2.2.5.5 Speed, Performance, Thrust Required versus Thrust Available at Sea Level

For detail of the analysis methods used for speed, performance, and thrust required versus thrust available at sea level, refer to "BFS 1.0 M lb. Seaplane Design and Performance" 1994 [3]. The results from this report are summarized below.

The drag and thrust data for sea level are shown in Figure 29. This data is the basis for the performance curves at sea level and is shown in Figure 30.

The maximum cruise speed can be seen as M=0.762, at the intersection of the thrust required and thrust available curves.

The maximum range cruise velocity is found at the tangent point of a line drawn from the origin with the thrust required curve. The maximum range cruise velocity for the 1.0 M lb. seaplane at sea level is M=0.43.

The maximum rate of climb can be found at the maximum difference between the thrust required and the thrust available curves. The distance between the two curves is called excess thrust.

**DRAG TABLE W/STEP: 1.0M Lb. Seaplane @ Sealevel**

| Mach | V | ρ | q | 1/q | CL | CL2 | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | slug/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | (W/(S*q))2 | CL2/(pi*AR*e) | | CDo+CDi | Cdtot*q*S |
| 0.1 | 111.64 | 0.002377 | 14.81 | 0.0675 | 5.6484 | 31.9040 | 1.2421 | 0.01663 | 1.2588 | 211,844 |
| 0.2 | 223.28 | 0.002377 | 59.25 | 0.0169 | 1.4121 | 1.9940 | 0.0776 | 0.01579 | 0.0934 | 62,888 |
| 0.4 | 446.56 | 0.002377 | 237.00 | 0.0042 | 0.3530 | 0.1246 | 0.0049 | 0.01444 | 0.0193 | 51,943 |
| 0.6 | 669.84 | 0.002377 | 533.24 | 0.0019 | 0.1569 | 0.0246 | 0.0010 | 0.01396 | 0.0149 | 90,383 |
| 0.7 | 781.48 | 0.002377 | 725.80 | 0.0014 | 0.1153 | 0.0133 | 0.0005 | 0.01443 | 0.0149 | 123,284 |
| 0.8 | 893.12 | 0.002377 | 947.98 | 0.0011 | 0.0883 | 0.0078 | 0.0003 | 0.01694 | 0.0172 | 185,732 |
| 0.9 | 1004.76 | 0.002377 | 1199.79 | 0.0008 | 0.0697 | 0.0049 | 0.0002 | 0.06296 | 0.0632 | 860,914 |

$$Thrust\_\mathrm{Re}quired = CD_{TOTAL} \cdot q \cdot S$$

$$CD_{TOTAL} = Cd_o + Cd_i$$

$$Cd_i = \frac{C_L^{\ 2}}{(\pi \cdot AR \cdot E)}$$

$$C_L = \frac{W}{(S \cdot q)}$$

**Figure 29. Base Case – 1.0 M lb. Seaplane drag calculations at sea level.**

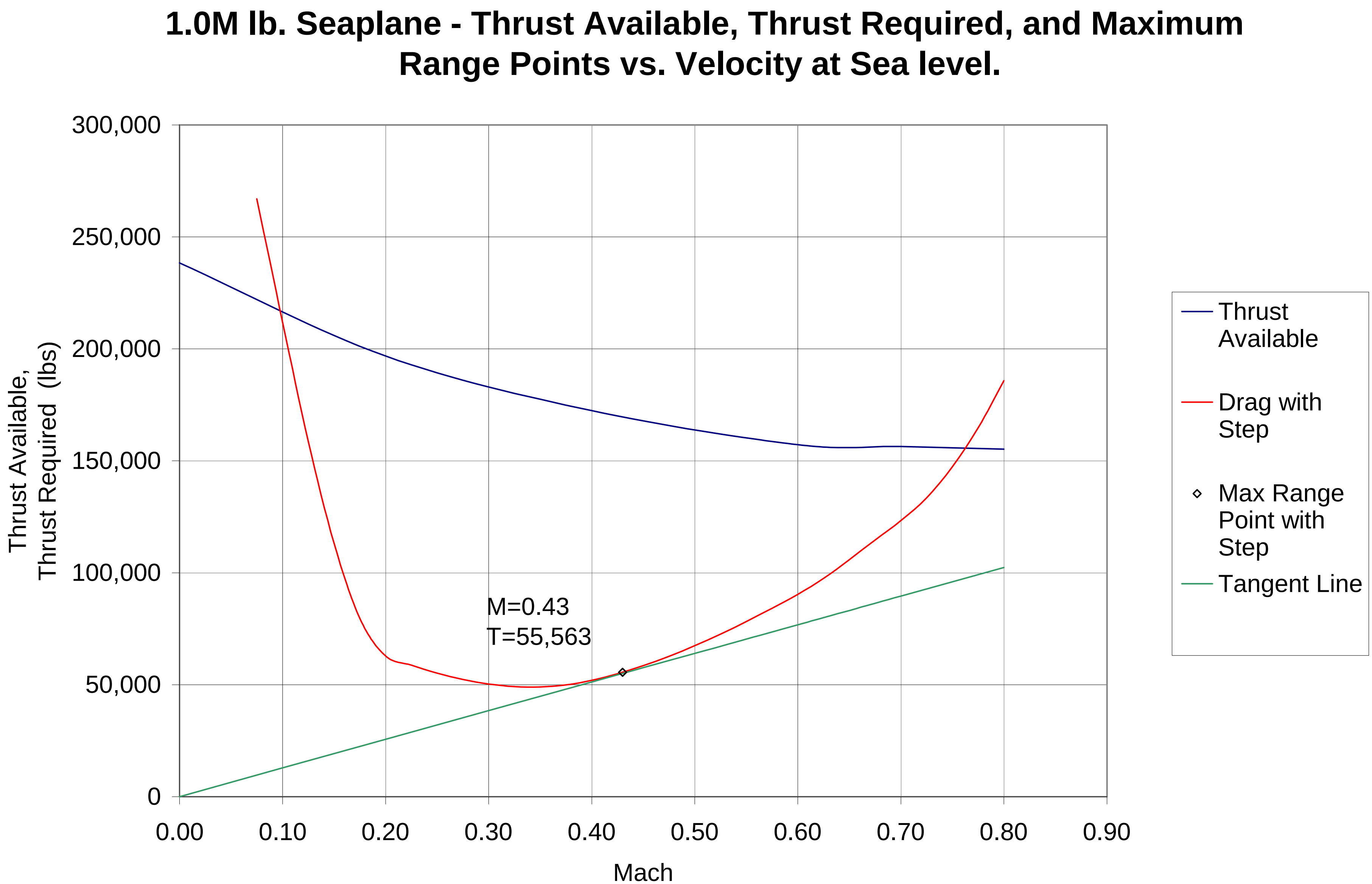



**Figure 30. Base Case – 1.0 M lb. Seaplane thrust available, thrust required vs. velocity and max range velocity at sea level**

### 2.2.5.6 Speed, Performance, Thrust Required versus Thrust Available at 30,000 ft.

For detail on the analysis used for speed, performance, and thrust required versus thrust available at 30,000 ft, refer to the 1994 report entitled “BFS 1.0 M lbs. Seaplane Design and Performance” [3].

The following is a summary of the report findings. The drag and thrust calculations are shown in Figure 31. The data from the drag and thrust calculations created Figure 32, which are the performance curves for the seaplane at 30,000 ft.

The maximum cruising speed for the seaplane is M=0.821. which is the intersection of the thrust required and thrust available curves.

The maximum range cruise velocity is found from the tangency of a line from the origin and the thrust required curve. The maximum range cruise velocity for the 1.0 M lb. seaplane at 30,000 ft is M=0.705.

The cruise lift to drag ratio (L/D) point for this study was taken as the maximum range point, M = 0.705. The cruise L/D for maximum range was found to be 18.99.

The rate of climb can be found as the distance between the thrust required and thrust available curves. The distance between the two curves is also called excess thrust.

**DRAG TABLE W/STEP: 1.0M Lb. Seaplane @ 30,000 ft.**

| Mach | V | ρ | q | 1/q | CL | CL2 | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | slug/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | (W/(S*q))2 | CL2/(pi*AR*e) | | CDo+CDi | Cdtot*q*S |
| 0.2 | 198.96 | 0.000891 | 17.63 | 0.0567 | 4.7458 | 22.5227 | 0.8769 | 0.01579 | 0.8927 | 178,803 |
| 0.4 | 397.92 | 0.000891 | 70.52 | 0.0142 | 1.1865 | 1.4077 | 0.0548 | 0.01444 | 0.0692 | 55,478 |
| 0.6 | 596.88 | 0.000891 | 158.66 | 0.0063 | 0.5273 | 0.2781 | 0.0108 | 0.01396 | 0.0248 | 44,681 |
| 0.7 | 696.36 | 0.000891 | 215.96 | 0.0046 | 0.3874 | 0.1501 | 0.0058 | 0.01443 | 0.0203 | 49,751 |
| 0.8 | 795.84 | 0.000891 | 282.07 | 0.0035 | 0.2966 | 0.0880 | 0.0034 | 0.01694 | 0.0204 | 65,269 |
| 0.9 | 895.32 | 0.000891 | 356.99 | 0.0028 | 0.2344 | 0.0549 | 0.0021 | 0.06296 | 0.0651 | 264,066 |

$$Thrust\_\mathrm{Re}quired = CD_{TOTAL} \cdot q \cdot S$$

$$CD_{TOTAL} = Cd_o + Cd_i$$

$$Cd_i = \frac{C_L{}^2}{(\pi \cdot AR \cdot E)}$$

$$C_L = \frac{W}{(S \cdot q)}$$

**Figure 31. Base Case 1.0 M lb. Seaplane drag calculations for cruise altitude of 30,000 ft.**

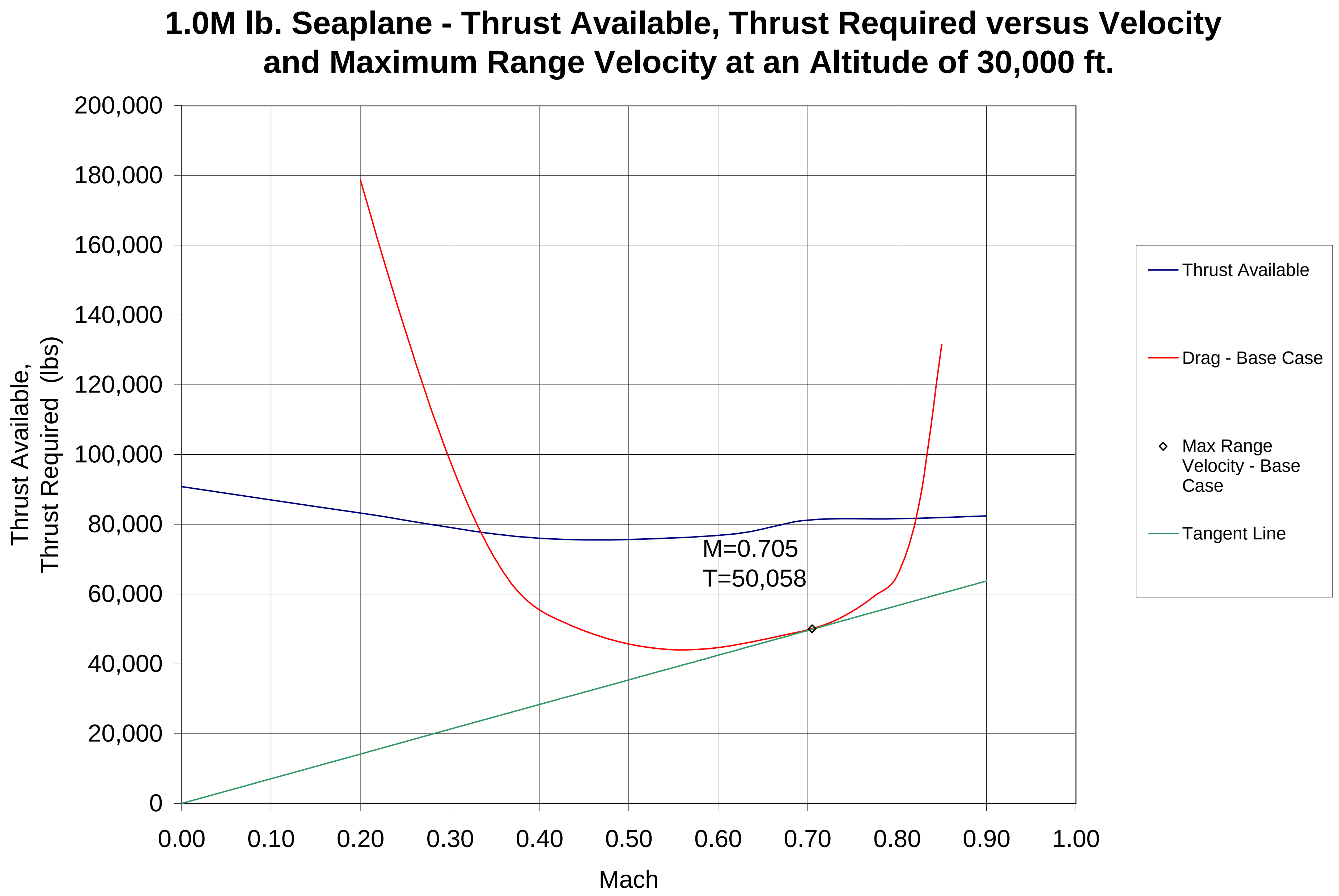



**Figure 32. Base Case – 1.0 M lb. Seaplane thrust available, thrust required vs. velocity and max range velocity for cruise altitude of 30,000 ft.**

### 2.2.5.7 Range versus Payload

The range of the 1.0 M lb. seaplane is calculated using the Brequet equation: $R_{cr} = \left(\frac{V}{C}\right) \cdot \left(\frac{L}{D}\right) \cdot \ln\left(\frac{W_{i-1}}{W_i}\right)$. From the previous section, the velocity at the maximum range and the lift to drag ratio are known. The specific fuel consumption is known through performance curves taken from the engine manufacturer. The change in weight from the beginning segment to the end segment is found from the calibrated Raymer based weight sizing spreadsheet. The results of the Brequet range equation calculations are shown below in Figure 33. The tabulated results show that the maximum range for the 1.0 M lb. seaplane for a ferry mission is 8,936 nm. A graphic plot of the results is given in Figure 34.

**1.0M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure - Base Case**

**Ferry Mission**

| | | |
|---|---|---|
| GTOW | 950,600 | lbs. |
| Empty | 470,432 | lbs. |
| Useful | 480,168 | lbs. |
| Crew | 1,800 | lbs. |
| 5% Reserve | 22,779 | lbs. |
| V | 415.53 | kts. |
| C | 0.539 | lbs./hr/lbs. |
| CD | 0.0201 | |
| CL | 0.3825 | |
| L/D | 19.01 | |
| $W_{i-1}$ | 925,725 | lbs. |
| $W_i$ | 503,226 | lbs. |

**Definitions**

Ferry Mission - Start, climb, cruise at best range cruise speed, loiter at sealevel for 30 minutes at optimum speed, and land without any fuel penalty.

GTOW - Gross Takeoff Weight
Empty - Empty weight
Useful - The difference between GTOW and Empty
V - Velocity in knots (M=0.705)
C - Total Specific Fuel Consumption

$W_{i-1}$ - Initial weight for segment (ignoring Climb&Accl.)
$W_i$ - Final weight for segment

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 8,936.2 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 478,368 |
| 1,220 | 360,000 |
| 3,652 | 225,418 |
| 6,351 | 100,000 |
| 8,936 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Altitude | 30,000 | ft | a | 994.8 | FT/SEC |
| | | | M | 0.705 | |
| | | | V=M*a | 701.334 | FT/SEC |
| C | 0.5388 | | V | 415.53 | KTS |

**Figure 33. Base Case – 1.0 M lb. Seaplane Range vs. Payload Calculations**

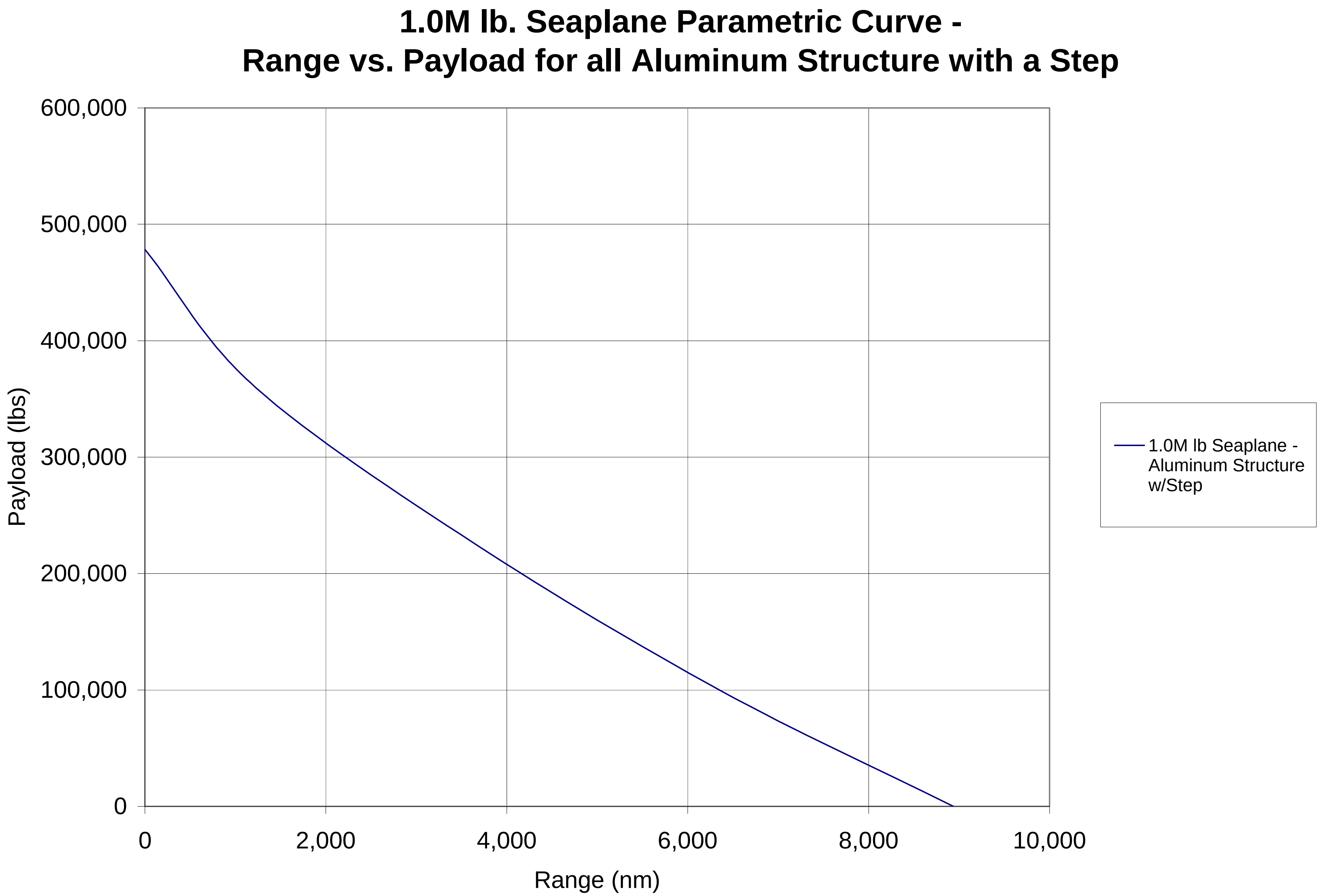



**Figure 34. Base Case – 1.0 M lb. Seaplane Range vs. Payload.**

### 2.2.6 2.9 M lb. Seaplane Base Case

#### 2.2.6.1 Specification

<u>BATTLE FORCE SEAPLANE - 2.9 M lbs.</u>
Type: 1,000,000 lb. Payload Airlift Seaplane

<u>CONSTRUCTION</u>: ALL ALUMINUM

<u>WINGS</u>: AIRFOIL, T/C=12% MAX T/C @ 0.4C
TRIPLE SLOTTED FOLWER FLAPS, SLATS OUTBOARD,
KRUEGER FLAPS INBOARD, (TRIMMED CL MAX - 2.8)

<u>FUSELAGE</u>: CONVENTIONAL SEMIMONOCOUQE, FAIL SAFE
STRUCTURE OF SKIN, STRINGERS, & RING FRAMES

<u>TAILS</u>:

| | |
|---|---|
| HORIZONTAL TAIL AIRFOIL - | NACA 0009 |
| VERTICAL TAIL AIRFOIL - | NACA 0009 |

<u>POWERPLANT</u>:

TEN PRATT & WHITNEY 4088 TURBOFAN ENGINES EACH RATED AT 90300 LB. TAKE-OFF THRUST

<u>ACOMODATION</u>: FOR BFS 2.9M LB. SEAPLANE

| | | | |
|---|---|---|---|
| TROOPS | = | 1950 | MAX |
| OR | | | |
| M-60A3 MAIN BATTLE TANKS | = | 8 | MAX |

<u>DIMENSIONS EXTERNAL</u>:

| | | |
|---|---|---|
| WING SPAN | = | 464 FT. 2 IN. |
| WING SWEEP | = | 28 DEGREES |
| WING ASPECT RATIO | = | 8.74 |
| DIHEDRAL | = | 1 DEGREE |
| LENGTH OVERALL | = | 403 FT. 4 IN. |
| LENGTH OF HULL | = | 363 FT. 4 IN. |
| BEAM | = | 33 FT. 4 IN. |
| HULL LENGTH / BEAM | = | 10.9 |
| FOREBODY LENGTH / HULL LENGTH | = | 0.553 |

### 2.2.6.1 Specification cont.

<u>DIMENSIONS INTERNAL</u>:

| | | |
|---|---|---|
| UPPER DECK FOREWARD ( L X W X H ) | = | 133 FT. X 25 FT. X 9 FT. |
| UPPER DECK AFT ( L X W X H ) | = | 85 FT. X 25 FT. X 9 FT. |
| LOWER CARGO DECK ( L X W X H ) | = | 241 FT. X 30 FT. X 20 FT. |

<u>FLOOR AREA</u>:

| | | |
|---|---|---|
| UPPER DECK FORWARD | = | 3,325 $FT.^2$ |
| UPPER DECK AFT | = | 2,125 $FT.^2$ |
| LOWER DECK, WITHOUT RAMP | = | 7,230 $FT.^2$ |

<u>VOLUME</u>:

| | | |
|---|---|---|
| UPPER DECK FORWARD | = | 19,152 $FT.^3$ |
| UPPER DECK AFT | = | 12,240 $FT.^3$ |
| LOWER CARGO DECK | = | 144,600 $FT.^3$ |

<u>AREAS</u>:

| | | |
|---|---|---|
| WING | = | 24,135 $FT.^2$ |
| HORIZONTAL TAIL | = | 4,715 $FT.^2$ |
| VERTICAL TAIL | = | 3,057 $FT.^2$ |

<u>STABILITY COEFFICIENTS</u>:

| | | |
|---|---|---|
| HORIZONTAL TAIL VOLUME COEF. | = | 0.630 |
| VERTICAL TAIL VOLUME COEF. | = | 0.073 |

<u>WEIGTS AND LOADINGS</u>

| | |
|---|---|
| GROSS TAKEOFF WEIGHT | 2,923,076 LBS. |
| EMPTY WEIGHT | 1,430,076 LBS. |
| DESIGN PAYLOAD | 1,000,000 LBS. |
| WING LOADING (MAX) | 118.95 LBS./$FT.^2$ |
| POWER LOADING T/W (MAX) | 0.309 |
| MAX FUEL LOAD WEIGHT | 1,491,200 LBS. |

### 2.2.6.1 Specification cont.

PERFORMANCE AT 30,000 FEET

(ESTIMATED AT MAX T.O. WIEGHT EXCEPT WHERE INDICATED)

| | | | | |
|---|---|---|---|---|
| MAXIMUM CRUISE SPEED | = | 458 | KTS. | (0.778M) |
| FUEL FLOW | = | 11,471 | LBS./HR. | |
| TSFC | = | 0.562 | KTS. | |
| BEST RANGE SPEED | = | 411 | KTS. | (.6975M) |
| FUEL FLOW | = | 10,909 | LBS./HR. | |
| TSFC | = | 0.536 | 1/HR. | |
| L/D | = | 22.21 | | |
| BEST ENDURANCE SPEED | = | 387 | KTS. | (0.657M) |
| FUEL FLOW | = | 10,369 | LBS./HR. | |
| TSFC | = | 0.521 | 1/HR. | |
| L/D | = | 22.96 | | |
| RANGE WITH 1,000,000 LBS. PAYLOAD AT BEST RANGE SPEED OF 411 KTS. WITH 1 HR. RESERVE | = | 2,246 | NM. | |
| FERRY RANGE AT BEST RANGE SPEED OF 411 KTS. WITH 1 HR. RESERVE | = | 10,609 | NM. | |

SEA LEVEL PERFORMANCE

| | | | |
|---|---|---|---|
| TAKE-OFF DISTANCE GROUND RUN | = | 5,887 | FT. |
| STALL SPEED | = | 112 | KTS. |
| TOUCH DOWN SPEED | = | 123 | KTS. |

## 2.2.6.2 Three View

BATTLE FORCE SEAPLANE - 2.9 M lbs.

Type: 1,000,000 lb. Payload Airlift Seaplane

CONSTRUCTION: ALL ALUMINUM

WINGS: AIRFOIL, T/C=12% MAX T/C @ 0.4C
TRIPLE SLOTTED FOLWER FLAPS, SLATS OUTBOARD, KRUEGER FLAPS INBOARD, (TRIMMED CL MAX - 2.8)

FUSELAGE: CONVENTIONAL SEMIMONOCOUQE, FAIL SAFE STRUCTURE OF SKIN, STRINGERS, & RING FRAMES

TAILS: HORIZONTAL TAIL AIRFOIL - NACA 0009
VERTICAL TAIL AIRFOIL - NACA 0009

POWERPLANT:
TEN TURBOFAN ENGINES EACH RATED AT 90,000+ LB. TAKE-OFF THRUST

ACOMODATION: FOR BFS 2.9M LB. SEAPLANE
TROOPS = 1950 MAX OR M-60A3 MAIN BATTLE TANKS= 8MAX

DIMENSIONS EXTERNAL:

| | | |
|---|---|---|
| WING SPAN | = | 464 FT. 2 IN. |
| WING SWEEP | = | 28 DEGREES |
| WING ASPECT RATIO | = | 8.74 |
| DIHEDRAL | = | 1 DEGREE |
| LENGTH OVERALL | = | 403 FT. 4 IN. |
| LENGTH OF HULL | = | 363 FT. 4 IN. |
| BEAM | = | 33 FT. 4 IN. |
| HULL LENGTH / BEAM | = | 10.9 |
| FOREBODY LENGTH / HULL LENGTH | = | 0.553 |

DIMENSIONS INTERNAL:

| | |
|---|---|
| UPPER DECK FOREWARD ( L X W X H ) | = 133 FT. X 25 FT. X 9 FT. |
| UPPER DECK AFT ( L X W X H ) = | 85 FT. X 25 FT. X 9 FT. |
| LOWER CARGO DECK ( L X W X H ) = | 241 FT. X 30 FT. X 20 FT. |

FLOOR AREA:
UPPER DECK FORWARD = 3,325 FT.2
UPPER DECK AFT = 2,125 FT.2
LOWER DECK, WITHOUT RAMP = 7,230 FT.2

| VOLUME: | AREAS: |
|---|---|
| UPPER DECK FORWARD = 19,152 FT.3 | WING = 24,135 FT.2 |
| UPPER DECK AFT = 12,240 FT.3 | HORIZONTAL TAIL = 4,715 FT.2 |
| LOWER CARGO DECK = 144,600 FT.3 | VERTICAL TAIL = 3,057 FT.2 |

STABILITY COEFFICIENTS:
HORIZONTAL TAIL VOLUME COEF. = 0.630
VERTICAL TAIL VOLUME COEF. = 0.073

WEIGTS AND LOADINGS
GROSS TAKEOFF WEIGHT=2,923,076 LBS EMPTY WEIGHT=1,430,076 LBS
DESIGN PAYLOAD=1,000,000 LBS
WING LOADING (MAX)=118.95 LBS./FT.2
POWER LOADING T/W (MAX)= 0.309
MAX FUEL LOAD WEIGHT=1,491,200LBS

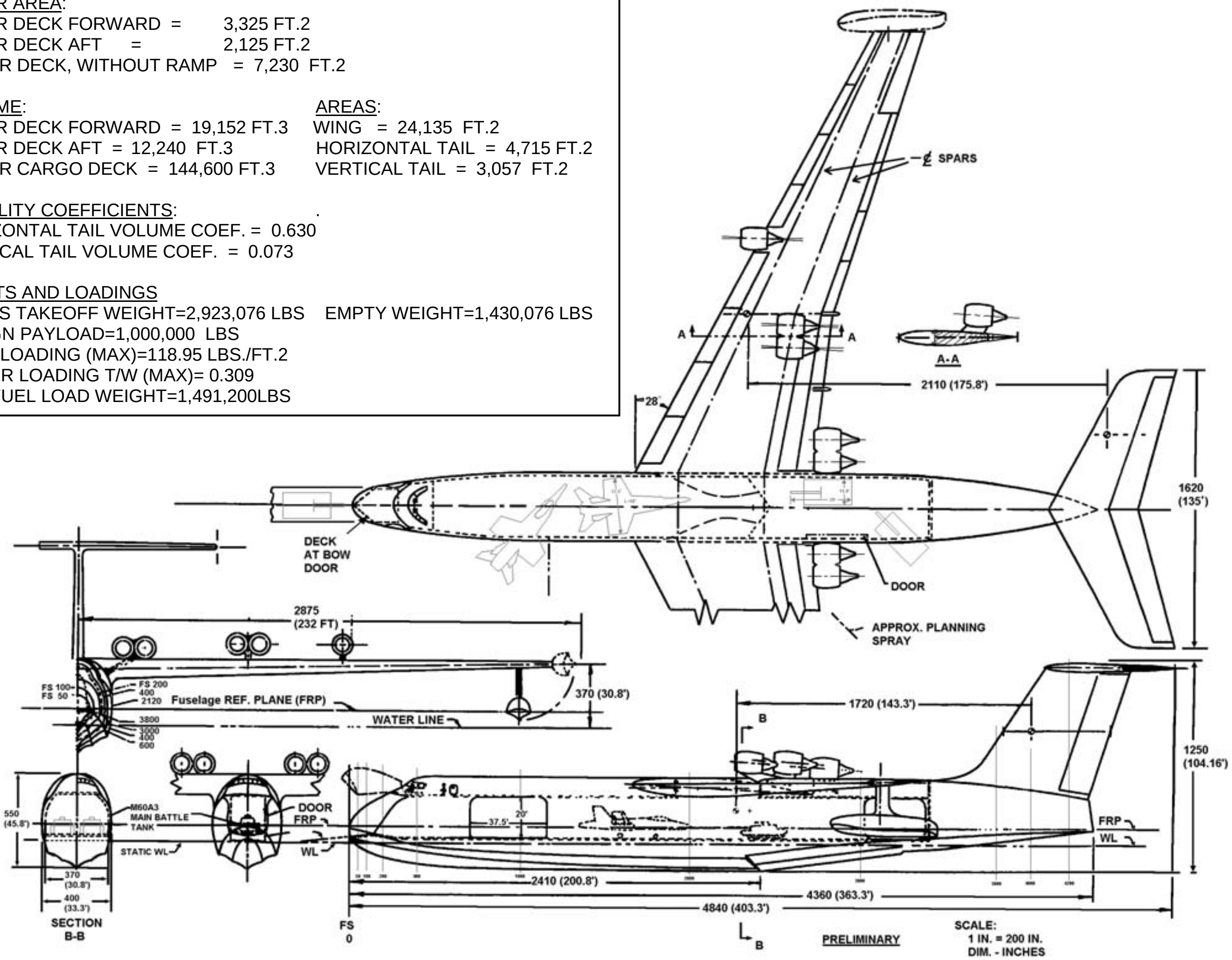



**Figure 35. 2.9 M lb Seaplane Three View**

### 2.2.6.3 Weight Breakdown

The weight analysis methods that were used are explained in section 2.2.2. The first analysis was completed at the Naval Warfare Center, Warminster in 1994. The analysis was performed using parametric equations developed from industry and conceptual design groups. For a detailed analysis of the weight breakdown for the 2.9 M lb seaplane, refer to the Naval Air Warfare Center report 1994 "BFS 2.9 M lb. Seaplane Design and Performance" [3]. For this report, the analysis was reproduced using the Raymer based empirical and parametric equations. The results of this analysis are shown below in Figure 36.

**2.9M lb. Seaplane - Base Case Weight Breakdown**

| | |
|---|---|
| Structure Group | 1,111,491 lbs. |
| Propulsion Group | 224,440 lbs. |
| Equipment Group | 94,145 lbs. |
| Empty Weight | 1,430,076 lbs. |
| Gross Take-off Weight | 2,923,076 lbs. |

**Figure 36. Base Case – 2.9 M lb. Seaplane weight breakdown**

### 2.2.6.4 Drag Breakdown

For detail on the analysis methods used for the drag breakdown, refer to [3]. The drag breakdown was refined for this report.

The calculation of the step drag was performed using National Advisory Committee for Aeronautics (NACA) reports and is shown in section 2.3.1.1. A summary of the results is given below in Figure 37.

**DRAG BREAKDOWN - COMPONENT METHOD**
**2.9 M lb. Seaplane**

| | M = 0.2 | M = 0.4 | M = 0.6 | M = 0.7 | M = 0.8 | M = 0.9 |
|---|---|---|---|---|---|---|
| **Component** | **Cdo** | **Cdo** | **Cdo** | **Cdo** | **Cdo** | **Cdo** |
| **Body** | 0.004150 | 0.003840 | 0.003820 | 0.003540 | 0.003510 | 0.003460 |
| **Step** | 0.000739 | 0.000739 | 0.000739 | 0.000739 | 0.000739 | 0.000739 |
| **V. Tail** | 0.000760 | 0.000677 | 0.000682 | 0.000682 | 0.000700 | 0.000730 |
| **H. Tail** | 0.001250 | 0.001150 | 0.001080 | 0.001080 | 0.001080 | 0.003840 |
| **Wing** | 0.005490 | 0.005080 | 0.004990 | 0.004980 | 0.017930 | 0.044930 |
| **Pontoons** | 0.000473 | 0.000440 | 0.000400 | 0.000380 | 0.000370 | 0.000370 |
| **Engines** | 0.001500 | 0.001300 | 0.001200 | 0.001200 | 0.001200 | 0.001200 |
| **Engine Mts.** | 0.000540 | 0.000520 | 0.000490 | 0.000490 | 0.000506 | 0.000520 |
| **Cdo** | 0.014902 | 0.013746 | 0.013401 | 0.013091 | 0.026035 | 0.055789 |
| **Protuberances** | X 1.1 | X 1.1 | X 1.1 | X 1.1 | X 1.1 | X 1.1 |
| **Total Cdo** | 0.0163922 | 0.0151206 | 0.0147411 | 0.0144001 | 0.0286385 | 0.0613679 |

**Figure 37. Base Case – 2.9 M lb. Seaplane Parasite Drag Breakdown.**

### 2.2.6.5 Speed, Performance, Thrust Required versus Thrust Available at Sea Level

For detail of the analysis methods used for speed, performance, and thrust required versus thrust available at sea level, see [3]. The results from the report were reproduced using our conceptual weight sizing and performance parametric and empirical equations. A detailed discussion of the conceptual aircraft sizing spreadsheet is presented in section 2.2.2.1.

The drag and thrust data for sea level are shown in Figure 38. This data was used to create the performance curves at sea level shown in Figure 39.

The maximum cruise speed is M=0.746. The maximum cruise speed is shown as the intersection between the thrust available and the thrust required performance curves.

The maximum range cruise velocity is found at the tangent point of a line drawn form the origin with the thrust required curve. The maximum range cruise velocity for the 2.9 M lb. seaplane at sea level is M=0.405.

The maximum rate of climb can be found at the maximum difference between the thrust required and the thrust available curves. The distance between the two curves is also called excess thrust.

**DRAG TABLE W/STEP: 2.9M Lb. Seaplane @ Sea Level**

| Mach | V | ρ | q | 1/q | CL | $CL^2$ | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | lbm/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | (W/S*q)^2 | CL^2/(pi*AR*e) | | CDo+CDi | Cdtot*q*S |
| 0.1 | 111.64 | 0.002377 | 14.81 | 0.0675 | 8.0302 | 64.4840 | 2.2256 | 0.01725 | 2.2429 | 816,430 |
| 0.2 | 223.28 | 0.002377 | 59.25 | 0.0169 | 2.0075 | 4.0303 | 0.1391 | 0.01639 | 0.1555 | 226,404 |
| 0.4 | 446.56 | 0.002377 | 237.00 | 0.0042 | 0.5019 | 0.2519 | 0.0087 | 0.01512 | 0.0238 | 138,693 |
| 0.6 | 669.84 | 0.002377 | 533.24 | 0.0019 | 0.2231 | 0.0498 | 0.0017 | 0.01474 | 0.0165 | 215,663 |
| 0.7 | 781.48 | 0.002377 | 725.80 | 0.0014 | 0.1639 | 0.0269 | 0.0009 | 0.01440 | 0.0153 | 273,362 |
| 0.8 | 893.12 | 0.002377 | 947.98 | 0.0011 | 0.1255 | 0.0157 | 0.0005 | 0.02864 | 0.0292 | 679,815 |
| 0.9 | 1004.76 | 0.002377 | 1199.79 | 0.0008 | 0.0991 | 0.0098 | 0.0003 | 0.06137 | 0.0617 | 1,819,393 |

$$Thrust\_Required = CD_{TOTAL} \cdot q \cdot S$$

$$CD_{TOTAL} = Cd_o + Cd_i$$

$$Cd_i = \frac{C_L^{\ 2}}{(\pi \cdot AR \cdot E)}$$

$$C_L = \frac{W}{(S \cdot q)}$$

**Figure 38. Base Case – 2.9 M lb. Seaplane drag calculations at sea level.**

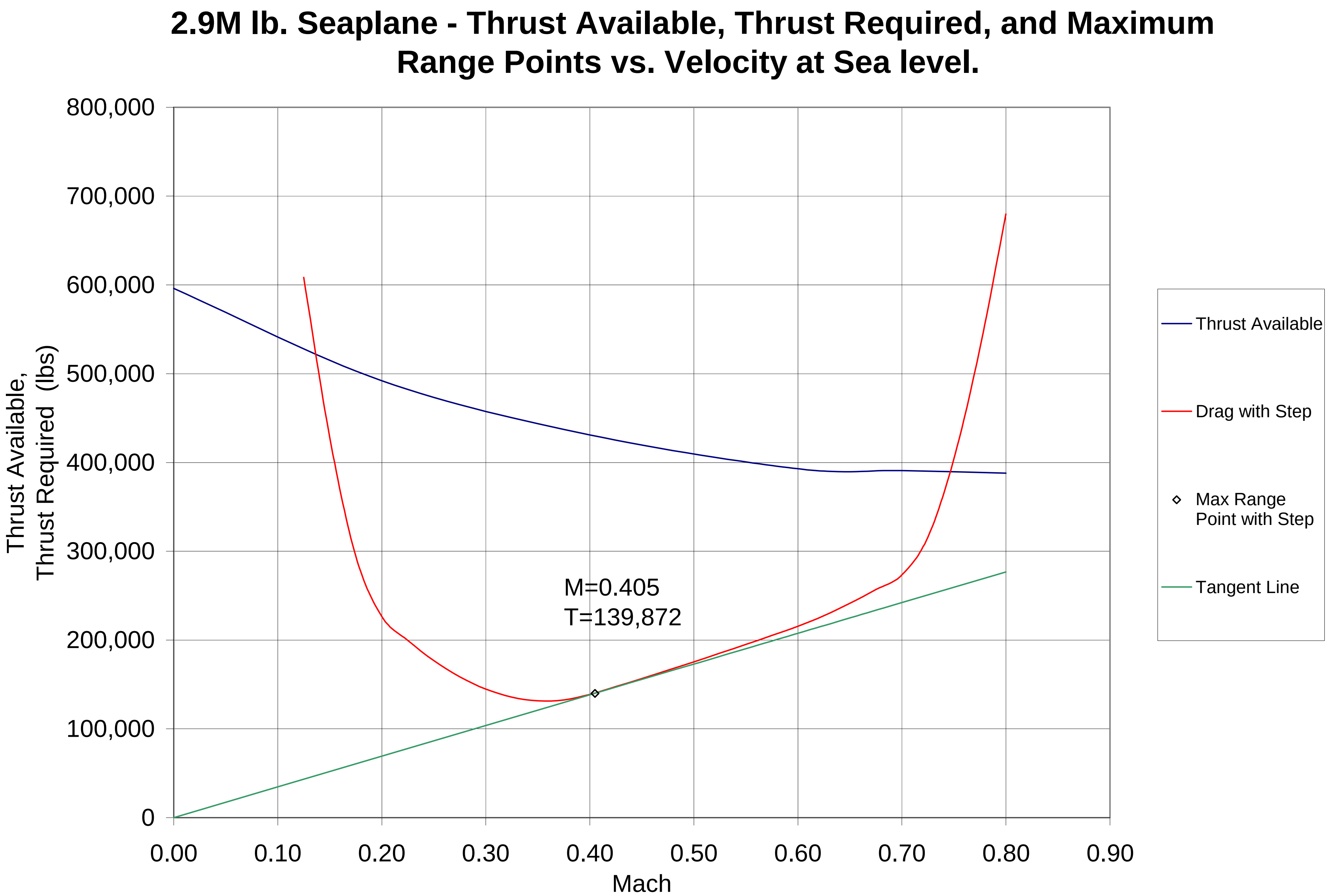



**Figure 39. Base Case – 2.9 M lb. Seaplane thrust required, thrust available vs. velocity and max range velocity for sea level.**

### 2.2.6.6 Speed, Performance, Thrust Required versus Thrust Available at 30,000 ft.

For a detailed analysis of the speed, performance, and thrust required versus thrust available at 30,000 ft. , see [3]. The following is a summary of our findings.

The drag and thrust calculations are shown in Figure 40. The data from the drag and thrust calculations was used to create Figure 41, which is a graph of the performance curves for the seaplane at 30,000 ft.

The maximum cruising speed for the 2.9 M lb. seaplane is M=0.778, which is the intersection of the thrust required and thrust available curves.

The maximum range cruise velocity is found from the tangency of a line from the origin and the thrust required curve. The maximum range cruise velocity for the 1.0 M lb. seaplane at 30,000 ft is M=0.698.

The cruise lift to drag ratio (L/D) point for this study was taken at the maximum range point, M = 0.698. The cruise L/D for maximum range was found to be 20.9.

The rate of climb can be found from the distance between the thrust required and thrust available curves at the maximum range point. The distance between the two curves is also called excess thrust.

**DRAG TABLE W/STEP: 2.9M Lb. Seaplane @ 30,000 ft.**

| Mach | V | ρ | q | 1/q | CL | $CL^2$ | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | lbm/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | (W/S*q)^2 | CL^2/(pi*AR*e) | | CDo+CDi | Cdtot*q*S |
| 0.2 | 198.96 | 0.0008907 | 17.63 | 0.0567 | 6.7470 | 45.522611 | 1.571183 | 0.01639 | 1.5876 | 687,798 |
| 0.4 | 397.92 | 0.0008907 | 70.52 | 0.0142 | 1.6868 | 2.845163 | 0.098199 | 0.01512 | 0.1133 | 196,377 |
| 0.6 | 596.88 | 0.0008907 | 158.66 | 0.0063 | 0.7497 | 0.562008 | 0.019397 | 0.01474 | 0.0341 | 133,111 |
| 0.7 | 696.36 | 0.0008907 | 215.96 | 0.0046 | 0.5508 | 0.303358 | 0.010470 | 0.01440 | 0.0249 | 131,991 |
| 0.8 | 795.84 | 0.0008907 | 282.07 | 0.0035 | 0.4217 | 0.177823 | 0.006137 | 0.02864 | 0.0348 | 241,060 |
| 0.9 | 895.32 | 0.0008907 | 356.99 | 0.0028 | 0.3332 | 0.111014 | 0.003832 | 0.06137 | 0.0652 | 571,999 |

$$Thrust\_Required = CD_{TOTAL} \cdot q \cdot S$$

$$CD_{TOTAL} = Cd_o + Cd_i$$

$$Cd_i = \frac{C_L^{\ 2}}{(\pi \cdot AR \cdot E)}$$

$$C_L = \frac{W}{(S \cdot q)}$$

**Figure 40. Base Case – 2.9 M lb. Seaplane drag calculations for cruise altitude 30,000 ft.**

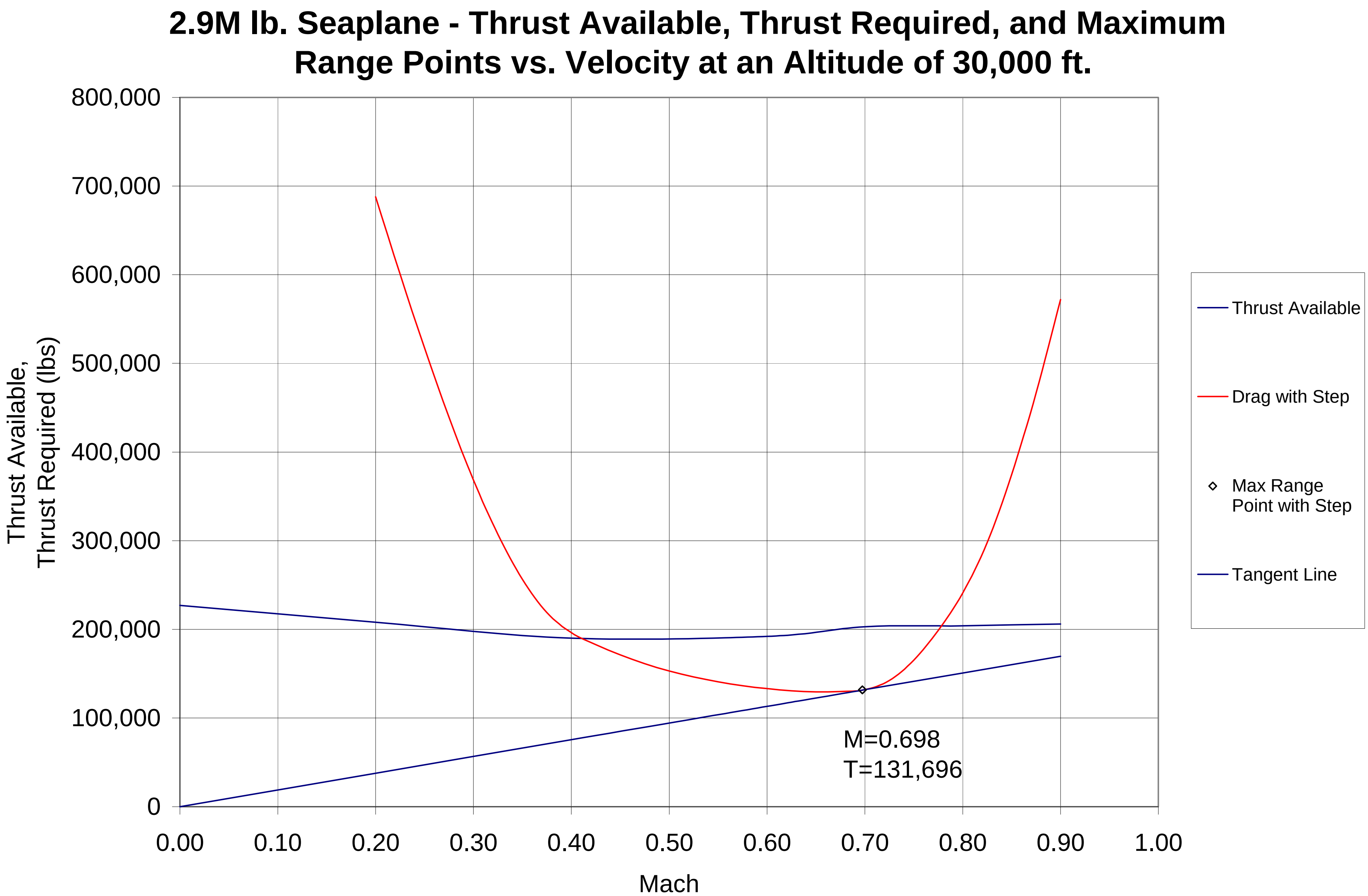



**Figure 41.  Base Case – 2.9 M lb. Seaplane drag, thrust available vs. velocity and max range velocity for cruise altitude of 30,000 ft.**

### 2.2.6.7 Range versus Payload

The range of the 2.9 M lb seaplane is calculated using the Brequet equation: $R_{cr} = \left(\frac{V}{C}\right)\cdot\left(\frac{L}{D}\right)\cdot\ln\left(\frac{W_{i-1}}{W_i}\right)$. From the previous section entitled "Speed, Performance, Thrust Required versus Thrust Available at 30,000 ft" the velocity at the maximum range and the lift to drag ratio are known. The specific fuel consumption is known through performance curves taken from the engine manufacturer. The change in weight from the beginning segment to the end segment is found from the calibrated Raymer based weight sizing spreadsheet. The results of the Brequet range equation calculations are shown below in Figure 42. The tabulated results show that the maximum range for the 2.9 M lb. seaplane for a ferry mission is 10,609 nm. A graphic plot of the results is given in Figure 43.

**2.9M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure - Base Case**

| **Ferry Mission** | | | **Definitions** |
|---|---|---|---|
| GTOW | 2,923,076 | lbs. | GTOW - Gross Takeoff Weight |
| Empty | 1,430,076 | lbs. | Empty - Empty weight |
| Useful | 1,493,000 | lbs. | Useful - The difference between GTOW and Empty |
| Crew | 1,800 | lbs. | |
| 5% Reserve | 71,010 | lbs. | Payload - Crew and 5% fuel reserve subtracted from the useful load |
| V | 411 | kts. | V - Velocity in knots (M=0.6975) |
| C | 0.54 | lbs./hr/lbs. | C - Specific Fuel Consumption |
| CD | 0.025 | | |
| CL | 0.554 | | |
| L/D | 22.21 | | |
| $W_{i-1}$ | 2,842,687 | lbs. | $W_{i-1}$ - Initial weight for segment |
| $W_i$ | 1,524,783 | lbs. | $W_i$ - Final weight for segment |

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 10,600.9 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 1,491,200 |
| 2,246 | 1,000,000 |
| 5,912 | 500,000 |
| 8,092 | 250,000 |
| 10,601 | 0 |

| | | | | |
|---|---|---|---|---|
| Altitude | 30,000 ft | a | 994.8 | FT/SEC |
| | | M | 0.6975 | |
| | | V=M*a | 693.87 | FT/SEC |
| C | 0.5364 | V | 411.11 | KTS |

**Figure 42. Base Case – 2.9 M lb. Seaplane range vs. payload calculations**

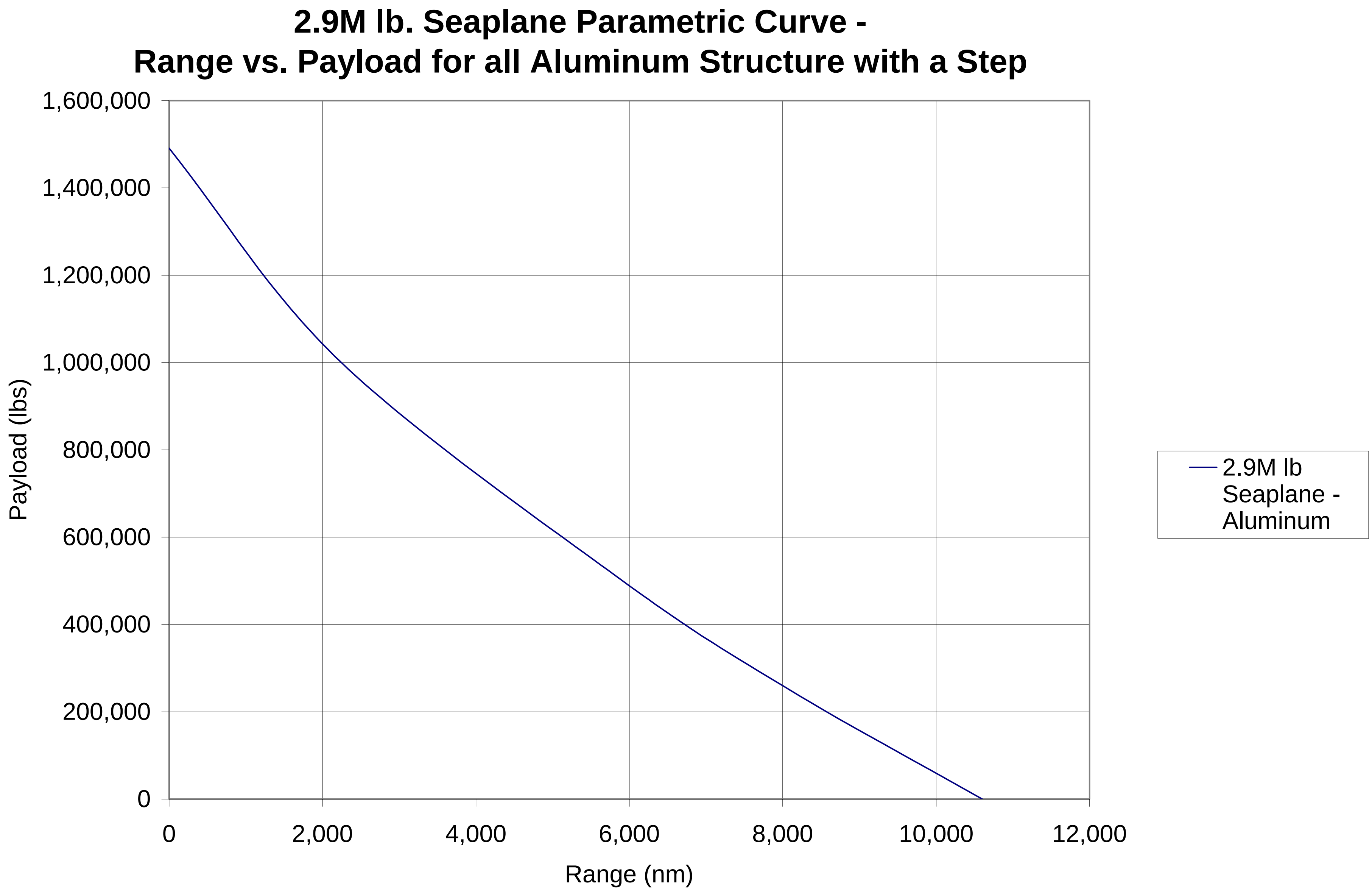



**Figure 43. Base Case – 2.9 M lb. Seaplane range vs. payload**

## 2.3 BASE CASE IMPROVED

### 2.3.1 Lower Drag

#### 2.3.1.1 Decrease Step Drag

Tests of seaplane hull designs have been conducted dating as far back as the 1920's. Everything from full-scale flight tests to model tests of various hull designs have been performed, with varying test results. These results have been studied for the purposes of this report, (see refs. 9, 11, and 12). Some results are shown as follows:

<u>Drag of Seaplane Step – Method 1</u>
BFS-1.0 M lb.

Ref.: Raymer, Daniel P. *Aircraft Design: A Conceptual Approach, Third Edition*. Reston, Va: American Institute of Aeronautics and Astronautics, Inc., 1999. pg. 350 [8].

Best Range and Speed: M = 0.705, 415.5 kts.

$$\Delta C_D = \frac{C_{D\pi} \cdot S_\pi}{S_w} \qquad f = C_{D\pi} \cdot S_\pi \qquad f = \frac{D}{q}$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.419(M - 0.161)^2\right] \cdot A_{base}$$

---

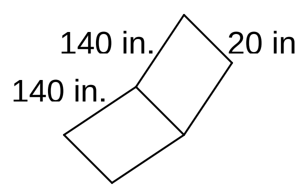
$S_W = 11{,}362\ ft^2$

$M = 0.705$

$A = 2 \cdot (20 \cdot 140)$

$A = 5600\,in^2$

$A = 38.9\ ft^2$




$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.419(0.705 - 0.161)^2\right] \cdot 38.9\ ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.124\right] \cdot 38.9\ ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.263\right] \cdot 38.9\ ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = 10.23\ ft^2$$

Drag of Seaplane Step cont.
BFS-1.0 M lb.

$$Subsonic\left(\frac{D}{q}\right)_{base} = 10.23\,ft^2 \qquad f = \frac{D}{q} \qquad f = C_{D\pi} \cdot S_{\pi} \qquad S_W = 11{,}362\,ft^2$$

$$\Delta C_{DStep} = \frac{C_{D\pi} \cdot S_{\pi}}{S_w} \qquad \Delta C_{DStep} = \frac{10.23\,ft^2}{11{,}362\,ft^2} \qquad \boxed{\Delta C_{DStep} = 0.0009004}$$

As a percentage of drag for the total aircraft, the step drag is as follows:

$$C_D = 0.014418$$

$$\Delta C_{DStep} = 0.0009004$$

$$\%C_D = \left(\frac{0.0009004}{0.014418}\right) \cdot 100$$

$$\boxed{\%C_D = 6.24\%}$$

Drag of Seaplane Step – Method 2
BFS-1.0 M lb.

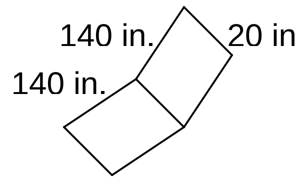
Ref: Hartman, Edwin P, *"The Aerodynamic Drag of a Flying-Boat Hull Model as Measured in the NACA 20-Foot Wind Tunnel 1"* National Advisory Committee for Aeronautics (NACA), Technical Note 525, April 1935 [9].

From TN 525 pg. 7:

"Step when expressed as a coefficient based on the area of the step gives a value which does not vary greatly and averages about 0.21…"

Step Area of Full Size Hull
Depth of Step – 5% of the Beam

$$Beam \cong 230 in.$$




$$Depth = 0.05 \cdot 230 in.$$
$$Depth = 11.5 in.$$
$$Step\_Area = 11.5 in. \cdot 280 in.$$
$$Step\_Area = 3{,}220 in.^2$$
$$Step\_Area = 22.36\, ft^2$$

<u>$C_{Do}$ Step Based on Step Area</u>

$$S_w = 11{,}362\, ft^2$$

$$\Delta C_{Do} = \frac{C_{D\Pi Model} \cdot A_{\Pi Full\_Scale}}{S_w}$$

$$\Delta C_{Do} = \frac{(0.21) \cdot (22.36\, ft^2)}{11{,}362\, ft^2} \qquad \boxed{\Delta C_{Do} = 0.000413}$$

As a percentage of drag for the total aircraft, the step drag is as follows:

$$\% C_D = \left( \frac{0.000413}{0.0143} \right) \cdot 100$$

$$\boxed{\% C_D = 2.88\%}$$

Drag of Seaplane Step – Method 3
BFS-1.0 M lb.

Ref.: Hoerner, Sighard F, *Fluid-Dynamic Drag*, 1992 pg. 13-9 Fig. 23 [10].

3rd Model – Retracted step $C_{Do} = 0.078$

4th Model – With step $C_{Do} = 0.092$

$\Delta C_{Do} = 0.092 - 0.078$

$\Delta C_{Do} = 0.014$ Based on Hull, $S_B = A_{\Pi Body}$

Relating to Full Scale Wing Area:

$S_w = 11{,}362\, ft^2$

$A_{\Pi Body} = 580\, ft^2$

$$C_{DStep} = \frac{C_{D\Pi} \cdot A_{\Pi}}{S_W}$$

$$C_{DStep} = \frac{(0.014) \cdot (580\, ft^2)}{11{,}362\, ft^2}$$

$$\boxed{C_{DStep} = 0.000714}$$

As a percentage of drag for the total aircraft, the step drag is as follows:

$$\% C_D = \left(\frac{0.000714}{0.0143}\right) \cdot 100$$

$$\boxed{\% C_D = 5\%}$$

Drag of Seaplane Step – Method 4
BFS-1.0 M lb.

Ref.: Conway, Robert N and Maynard, Julian D. *Wind-Tunnel Tests of Four Full-Scale Seaplane Floats,* ARR 3G15 Langley Field, July, 1943 [11].

Comparison with NACA Advance Restricted Report (ARR) No. 3615 "Wind Tunnel Testing on Four Full Scale Seaplane Floats" which gives the following:

> "A step fairing which might conceivably be made retractable reduced the drag of the Edo 68F Float more than 10 percent and a four foot tail extension on the blunt-stern Edo 62-6560 float reduced the drag 8 percent."

We will investigate the step only at Mach 0.7.

$Body\_drag = 0.00277$

$Step = 0.0009004$

$Total\_Hull\_Drag = 0.0036704$

$Step\_10\%\_of\ \_Hull\_Drag = 0.10 \cdot 0.0036704$ Step 10% of Hull Drag

$\boxed{C_{DStep} = 0.00036704}$

Drag of Complete Aircraft is 0.014388.

As a percentage of drag for the total aircraft to the increment drag, $C_{Dstep}$, of the step drag is as follows:

$$\%C_D = \frac{0.00036704}{0.014388}$$

$\boxed{\%C_D = 2.55\%}$

Comparison of Method Results of Step Drag

| | | | |
|---|---|---|---|
| 1. | Raymer Equation | $\boxed{C_{DStep} = 0.0009004}$ | $\boxed{\%C_D = 6.24\%}$ |
| 2. | NACA TN 525 | $\boxed{C_{DStep} = 0.000714}$ | $\boxed{\%C_D = 2.88\%}$ |
| 3. | Hoerner | $\boxed{C_{Do} = 0.000413}$ | $\boxed{\%C_D = 5\%}$ |
| 4. | NACA ARR 3G15 | $\boxed{C_{DStep} = 0.00036704}$ | $\boxed{\%C_D = 2.55\%}$ |

## 2.3.2 Reduce Overall Weight

### 2.3.2.1 Weight Savings Through the Use of Composites

Weight savings through alternate use of material is a subject of great scope. It depends on the type of aircraft, the mission for the aircraft, etc. In general, composites, or advanced composites such as epoxy-graphite fiber laminates, have a much higher strength to weight ratio than aluminum. Epoxy glass fiber composites are stronger and lighter than aluminum, and have proven to be better in salt water than aluminum or graphite epoxy. There are differences of opinion as to the exact magnitude of the weight savings, but it is the writer's opinion that there is general agreement that composites are superior to aluminum. Typical weight savings for various aircraft are listed below in Figure 44:

| Type of Structure | Component | Weight Saving, % |
|---|---|---|
| Secondary | McDonnell-Douglas DC-10 rudder | 26.8 |
| | Boeing 727 elevator | 25.6 |
| | Lockheed L-1011 aileron | 26.3 |
| Primary | McDonnell-Douglas DC-10 vertical tail | 20.2 |
| | Boeing 737 horizontal tail | 27.1 |
| | Lockheed L-1011 vertical tail | 27.9 |

**Figure 44. Typical weight savings using composites for various aircraft.**

Dan Raymer, the well know aircraft designer and writer of many text books, such as "Aircraft Design a Conceptual Approach" states" The greatest revolution in aircraft structures…. has been the on going adoption of composites materials for primary structure in a typical aircraft part, the direct substitution of graphite – epoxy composites for aluminum yields a weight saving of 25%." [7, pg.43]

In recent talks with NAVAIR engineers in the Mass Properties department, the following general weight savings from using composites for various structural components are given below:

Wing Weight = 10% of Structure
Tail Surfaces = 10%
Fuselage = 9%

There are differences of opinion in providing a concrete value as to the weight savings in using composite materials in place of aluminum. The author of this paper shows the effect in aircraft performance for a range in weight savings, that of 15% and 25%

### 2.3.2.2 Laminar Flow (low drag), A Byproduct of Composites

There are many examples of the ability to achieve laminar flow through the use of composites. Because of composites, it has been possible to manufacture very large structural components in one seamless piece without rivets, without waves in the skin surfaces, etc. With such surfaces it is possible to manufacture an airplane that has a drag coefficient of 0.015, where its counterpart in aluminum might have a coefficient of 0.025. This is a tremendous advantage, giving the aircraft more speed and range.

### 2.3.2.3 Strength of Composites

Shown in Figure 45, is an analysis from the book, "Aircraft Structures" by Peery [2]. It is a summary of the ratio of a material weight to the weight of 24S-T aluminum alloy (to withstand the same load).

| Sheet material (1) | $F$, psi (approx.) (2) | $w$, lb/in.$^3$ (3) | $E$, 1,000 psi (4) | Ratio of weight to the weight of 24S–T aluminum alloy | | |
|---|---|---|---|---|---|---|
| | | | | Tension $\frac{w_1}{w_2}\frac{F_2}{F_1}$ (5) | Bending $\frac{w_1}{w_2}\sqrt{\frac{F_2}{F_1}}$ (6) | Compression buckling $\frac{w_1}{w_2}\sqrt[3]{\frac{E_2}{E_1}}$ (7) |
| Stainless steel | 185,000 | 0.286 | 26,000 | 1.23 | 1.72 | 2.12 |
| Aluminum alloy 24S–T | 66,000 | 0.100 | 10,500 | 1.00 | 1.00 | 1.00 |
| Aluminum alloy 75S–T | 77,000 | 0.101 | 10,400 | 0.87 | 0.93 | 1.01 |
| Magnesium alloy | 40,000 | 0.065 | 6,500 | 1.07 | 0.83 | 0.77 |
| Laminated plastic | 30,000 | 0.050 | 2,500 | 1.10 | 0.74 | 0.83 |
| Spruce wood | 9,400 | 0.0156 | 1,300 | 1.09 | 0.42 | 0.31 |

**Figure 45. Ratio of material weight to aluminum alloy 24S-T weight.**

The strength of advanced composites depends on the type of fiber and resin matrix. The composite types for aircraft are mostly graphite fiber epoxy laminate fabricated under heat and pressure. The following calculations compare graphite epoxy composite to aluminum alloy 24S-T in tension, bending, and compression.

Material Properties of Graphite Epoxy and Aluminum 24S-T

$$\rho_{comp.} = 0.056\frac{lb}{in^3} \qquad F_{TUcomp.}(L) = 180{,}000\frac{lb}{in^2}$$

$$\rho_{alum.} = 0.100\frac{lb}{in^3} \qquad F_{TUalum.} = 66{,}000\frac{lb}{in^2}$$

Fiber Orientation - 0°

The ratio of graphite epoxy composite weight to aluminum 24S-T weight to carry the same tensile load is illustrated below.

TENSION – Strength to Weight Relationship of Graphite Epoxy Composite Relative to Aluminum Alloy 24S-T

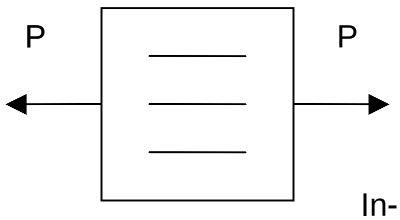
$$\frac{W_{comp.}}{W_{alum.}} = \frac{\rho_{comp.}}{\rho_{alum.}}\cdot\frac{F_{TUalum.}}{F_{TUcomp.}} \qquad \frac{W_{comp.}}{W_{alum.}} = \left(\frac{0.056\frac{lb}{in^3}}{0.100\frac{lb}{in^3}}\right)\cdot\left(\frac{66{,}000\frac{lb}{in^2}}{180{,}000\frac{lb}{in^2}}\right) \qquad \boxed{\frac{W_{comp.}}{W_{alum.}} = 0.2}$$

Orienting the fibers at 45° to the direction of the applied load; testing the shear strength of the graphite epoxy composite is given below.

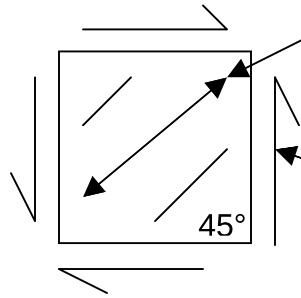
In the shear direction the ultimate stress is: $F_{TUcomp} = 23{,}200\frac{lb}{in^2}$

$$\frac{W_{comp.}}{W_{alum.}} = \frac{\rho_{comp.}}{\rho_{alum.}}\cdot\frac{F_{TUalum.}}{F_{TUcomp.}} \qquad \frac{W_{comp.}}{W_{alum.}} = \left(\frac{0.056\frac{lb}{in^3}}{0.100\frac{lb}{in^3}}\right)\cdot\left(\frac{66{,}000\frac{lb}{in^2}}{23{,}200\frac{lb}{in^2}}\right) \qquad \boxed{\frac{W_{comp.}}{W_{alum.}} = 1.59}$$

Notice that the graphite epoxy composite is weaker than aluminum in shear, but composites are designed to orient the fibers along the known load paths.




In-Plane Tension




Optimum Fiber Direction

In-Plane Shear

q (shear flow) lb/in

BENDING – Strength to Weight Relationship of Graphite Epoxy Composite Relative to Aluminum Alloy 24S-T

$$\frac{W_{comp.}}{W_{alum.}} = \frac{\rho_{alum.}}{\rho_{comp.}} \cdot \sqrt{\frac{F_{TUalum.}}{F_{TUcomp.}}} \qquad \frac{W_{comp.}}{W_{alum.}} = \frac{0.056\frac{lb}{in^3}}{0.100\frac{lb}{in^3}} \cdot \sqrt{\frac{66{,}000\frac{lb}{in^2}}{180{,}000\frac{lb}{in^2}}} \qquad \boxed{\frac{W_{comp.}}{W_{alum.}} = 0.34}$$

COMPRESSION/BUCKLING – Strength to Weight Relationship of Graphite Epoxy Composite Relative to Aluminum Alloy 24S-T

$$\frac{W_{comp.}}{W_{alum.}} = \frac{\rho_{alum.}}{\rho_{comp.}} \cdot \sqrt[3]{\frac{E_{alum.}}{E_{comp.}}} \qquad \frac{W_{comp.}}{W_{alum.}} = \frac{0.056\frac{lb}{in^3}}{0.100\frac{lb}{in^3}} \cdot \sqrt[3]{\frac{21{,}000{,}000\frac{lb}{in^2}}{10{,}500{,}000\frac{lb}{in^2}}} \qquad \boxed{\frac{W_{comp.}}{W_{alum.}} = 0.45}$$

### 2.3.2.4 Some US Military Aircraft Using Composites

| | |
|---|---|
| F-15 Eagle | Horizontal and Vertical Stabilizers |
| F-14 Tomcat | Horizontal Stabilizer |
| B-1B Lancer | Longeron |
| X-29 | External Wing Structure |
| AV-8B Harrier | Wing |
| V-22 Osprey | Airframe, propellers, and rotors |

### 2.3.3 0.3 M lb. Seaplane Improved

#### 2.3.3.1 Drag Reduction

Due to the short time frame for the study, a simplified analysis method was performed to obtain the drag. The parasite drag was estimated using the equivalent flat plate method found in Roskam's "Airplane Design, Part I" [6]. The equivalent flat plate area is found from Figure 19. Overlaid on the figure are the wetted area for the 0.3 M lb. seaplane and the resulting equivalent flat plate area of 60 ft$^2$. This value was used in the following formula: $C_{Do} = \frac{f}{S}$, where f is the equivalent flat plate area and S is the wing area. The total drag, $C_D$, of the airplane includes induced drag was calculated as: $C_D = C_{Do} + \frac{C_L{}^2}{\pi \cdot e \cdot AR}$. This gave the drag polar, and from this drag polar the thrust required curve was obtained. The thrust required curves are generated for the base case seaplane configuration with a step.

The item of drag most productive for drag reduction was the step in the bottom of the seaplane hull. The step drag calculation is shown in section 2.3.1.1. The analysis to decrease the step drag was calculated by reference to NACA reports. The step drag was subtracted from the parasite drag portion and the results were plotted along with the base case thrust required curve. It is to be understood that without a step means a retractable step in the retracted position.

#### 2.3.3.1.1 Step Drag Calculation

The item of drag most productive for decreased drag was the step in the bottom of the seaplane hull. A sample step drag calculation is shown in section 2.3.1.1 “Decrease Step Drag”. Of the four methods looked at the Raymer base drag equation was easiest to apply to the three seaplanes. The following step drag calculations use this method.

<u>Drag of Seaplane Step – Method 1</u>
BFS-0.3 M lb.

Best Range and Speed: M = 0.58, 356 kts.

$$\Delta C_D = \frac{C_{D\pi} \cdot S_\pi}{S_w} \qquad f = C_{D\pi} \cdot S_\pi \qquad f = \frac{D}{q}$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.419(M - 0.161)^2\right] \cdot A_{base}$$

---

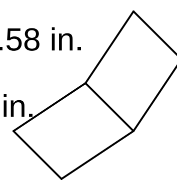
$$S_W = 2,650 \quad ft^2$$

$$M = 0.58$$

$$A = 2 \cdot (92.58 \cdot 12.9)$$

$$A = 2388 in^2$$

$$A = 16.59 ft^2$$




$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.419(0.58 - 0.161)^2\right] \cdot 16.59 ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.0736\right] \cdot 16.59 ft^2 \qquad Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.213\right] \cdot 16.59 ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = 3.53 ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = 3.53 ft^2 \qquad f = \frac{D}{q} \qquad f = C_{D\pi} \cdot S_\pi \qquad S_W = 2,650 ft^2$$

$$\Delta C_{DStep} = \frac{C_{D\pi} \cdot S_\pi}{S_w} \qquad \Delta C_{DStep} = \frac{3.53 ft^2}{2,650 ft^2} \qquad \boxed{\Delta C_{DStep} = 0.00133}$$

#### 2.3.3.1.2 $C_D$ with a Fixed Step

The total drag for the BFS-0.3 M lb. seaplane with a step at cruise altitude for various mach numbers is shown below in Figure 46. The cruise velocity at an altitude of 20,000 is Mach 0.58.

**0.3M Lb. Seaplane @ 20,000 ft.-STEP**

| Mach | CDi | CDo | $CD_{total}$ |
|---|---|---|---|
| 0.2 | 0.5431 | 0.023 | 0.5661 |
| 0.3 | 0.1073 | 0.023 | 0.1303 |
| 0.4 | 0.0339 | 0.023 | 0.0569 |
| 0.5 | 0.0139 | 0.023 | 0.0369 |
| 0.6 | 0.0067 | 0.023 | 0.0297 |
| 0.7 | 0.0036 | 0.023 | 0.0266 |
| 0.8 | 0.0021 | 0.023 | 0.0251 |

**Figure 46. Base Case – 0.3 M lb. Seaplane total drag.**

#### 2.3.3.1.3 $C_D$ with a Retracted Step

The total drag for the BFS-0.3 M lb. seaplane without a step at cruise altitude for various mach numbers is shown below in Figure 47. The cruise velocity without a step at an altitude of 20,000 is Mach 0.58.

**0.3M Lb. Seaplane @ 20,000 ft. - NO STEP**

| Mach | CDi | CDo | $CD_{total}$ |
|---|---|---|---|
| 0.2 | 0.5431 | 0.02167 | 0.5648 |
| 0.3 | 0.1073 | 0.02167 | 0.1290 |
| 0.4 | 0.0339 | 0.02167 | 0.0556 |
| 0.5 | 0.0139 | 0.02167 | 0.0356 |
| 0.6 | 0.0067 | 0.02167 | 0.0284 |
| 0.7 | 0.0036 | 0.02167 | 0.0253 |
| 0.8 | 0.0021 | 0.02167 | 0.0238 |

**Figure 47. Improved Case – 0.3 M lb. Seaplane total drag.**

### 2.3.3.1.4 Table - Thrust Required with a Fixed Step and with a Retracted Step

For the drag calculations for the BFS-0.3 M lb. seaplane with and without a step; see Figure 48 below. To illustrate the effect that the step has on performance is shown in Figure 49. The maximum cruising speed for the 0.3 M lb. seaplane without a step is M=0.634 or 657 knots, increased from M=0.619 or 643 knots. The maximum cruise speed attainable increased 15 knots by removing the step. The maximum range cruise velocity for the seaplane without as step was M=0.58, the same as with the step. The L/D ratio for the seaplane without the step at the maximum range point is 14.59, which is an increase from the step L/D of 13.95.

**DRAG TABLE: 0.3m Lb. Seaplane @ 20,000 ft.**

| Mach | V | ρ | q | 1/q | CL | $CL^2$ | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | lbm/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | $(W/(S*q))^2$ | $CL^2/(pi*AR*e)$ | | CDo+CDi | CDtot*q*S |
| 0.2 | 207.38 | 0.00126643 | 27.23 | 0.03672096 | 3.6029 | 12.9805 | 0.5431 | 0.023 | 0.5661 | 40856 |
| 0.3 | 311.07 | 0.00126643 | 61.27 | 0.01632043 | 1.6013 | 2.5641 | 0.1073 | 0.023 | 0.1303 | 21155 |
| 0.4 | 414.76 | 0.00126643 | 108.93 | 0.00918024 | 0.9007 | 0.8113 | 0.0339 | 0.023 | 0.0569 | 16438 |
| 0.5 | 518.45 | 0.00126643 | 170.20 | 0.00587535 | 0.5765 | 0.3323 | 0.0139 | 0.023 | 0.0369 | 16645 |
| 0.6 | 622.14 | 0.00126643 | 245.09 | 0.00408011 | 0.4003 | 0.1603 | 0.0067 | 0.023 | 0.0297 | 19293 |
| 0.7 | 725.83 | 0.00126643 | 333.60 | 0.00299763 | 0.2941 | 0.0865 | 0.0036 | 0.023 | 0.0266 | 23532 |
| 0.8 | 829.52 | 0.00126643 | 435.72 | 0.00229506 | 0.2252 | 0.0507 | 0.0021 | 0.023 | 0.0251 | 29007 |

**DRAG TABLE W/O STEP: 0.3m Lb. Seaplane @ 20,000 ft.**

| Mach | V | ρ | q | 1/q | CL | $CL^2$ | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | lbm/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | $(W/(S*q))^2$ | $CL^2/(pi*AR*e)$ | | CDo+CDi | CDtot*q*S |
| 0.2 | 207.38 | 0.00126643 | 27.23 | 0.03672096 | 3.6029 | 12.9805 | 0.5431 | 0.02167 | 0.5648 | 40760 |
| 0.3 | 311.07 | 0.00126643 | 61.27 | 0.01632043 | 1.6013 | 2.5641 | 0.1073 | 0.02167 | 0.1290 | 20939 |
| 0.4 | 414.76 | 0.00126643 | 108.93 | 0.00918024 | 0.9007 | 0.8113 | 0.0339 | 0.02167 | 0.0556 | 16054 |
| 0.5 | 518.45 | 0.00126643 | 170.20 | 0.00587535 | 0.5765 | 0.3323 | 0.0139 | 0.02167 | 0.0356 | 16045 |
| 0.6 | 622.14 | 0.00126643 | 245.09 | 0.00408011 | 0.4003 | 0.1603 | 0.0067 | 0.02167 | 0.0284 | 18430 |
| 0.7 | 725.83 | 0.00126643 | 333.60 | 0.00299763 | 0.2941 | 0.0865 | 0.0036 | 0.02167 | 0.0253 | 22357 |
| 0.8 | 829.52 | 0.00126643 | 435.72 | 0.00229506 | 0.2252 | 0.0507 | 0.0021 | 0.02167 | 0.0238 | 27471 |

**Figure 48. Improved Case – 0.3 M lb. Seaplane thrust required with a fixed step and with a retracted step for cruise altitude of 20,000 ft.**

### *2.3.3.1.5 Chart – Thrust Required with a Fixed Step and with a Retracted Step*

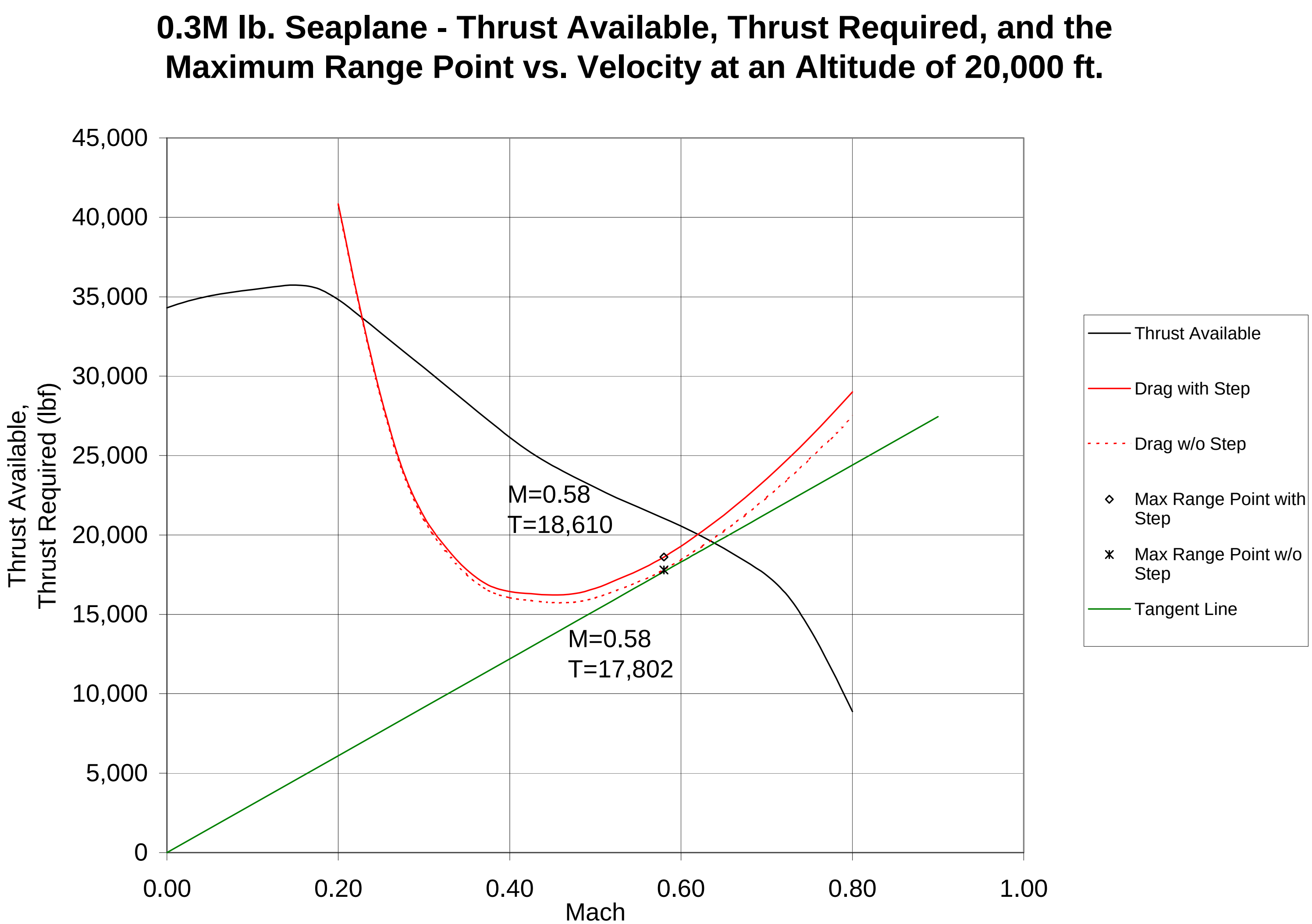



**Figure 49. Improved Case – 0.3 M lb. Seaplane drag, thrust required max range velocity with a fixed step and with a retracted step for a cruise altitude of 20,000 ft.**

### 2.3.3.1.6 Range Payload with a Fixed Step and with a Retracted Step

The following is a comparison of the range versus payload for the 0.3 M lb. seaplane with and without the step. The range was calculated using the Brequet equation: $R_{cr} = \left(\frac{V}{C}\right)\cdot\left(\frac{L}{D}\right)\cdot\ln\left(\frac{W_{i-1}}{W_i}\right)$. From the previous section entitled "Chart – Thrust Required with a Fixed Step and with a Retracted Step" the velocity at the maximum range and the lift to drag ratio were known. The specific fuel consumption is known through performance curves taken from the engine manufacturer. The change in weight from the beginning segment to the end segment is found from the calibrated Raymer based weight sizing spreadsheet. The results of the Brequet range equation calculations are shown in Figures 50 and 51. A summary of the range results is given below

| 0.3 M lb. Seaplane | |
|---|---|
| Range without step: | 6,765 nm. |
| Range with step: | 6,576 nm. |
| Difference | 189 nm. |

The BFS-0.3 M lb. seaplane can extend its range by 189 nm., if it had a retractable step installed. Figure 52 shows this difference graphically.

**0.3M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure - Base Case**

**Ferry Mission**

| | | | |
|---|---|---|---|
| GTOW | 260,003 | lbf. | GTOW - Gross Takeoff Weight |
| Empty | 127,244 | lbf. | Empty - Empty weight |
| Useful | 132,759 | lbf. | Useful - The difference between GTOW and Empty |
| Crew | 1,000 | lbf. | |
| 5% Reserve | 6,274 | lbf. | |
| V | 356.32 | kts. | V - Velocity in knots (M=0.58) at 20,000 ft. |
| C | 0.468 | lbf./hr/lbf. | C - Total Specific Fuel Consumption |
| CD | 0.0307 | lbf. | |
| CL | 0.4277 | lbf. | |
| L/D | 13.95 | | |
| $W_{i-1}$ | 253,971 | lbf. | $W_{i-1}$ - Initial weight for segment. |
| $W_i$ | 136,781 | lbf. | $W_i$ - Final weight for segment. |

**Brequet Range Equation**

$$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$$

$R_{cr}$ = 6575.6 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 131,759 |
| 1,336 | 90,000 |
| 2,812 | 60,000 |
| 4,526 | 30,000 |
| 6,576 | 0 |

| | | | |
|---|---|---|---|
| Altitude | 20,000 ft | a | 1036.9 FT/SEC |
| | | M | 0.58 |
| | | V=M*a | 601.402 FT/SEC |
| C | 0.4679 | V | 356.32 KTS |

**Figure 50. Base Case – 0.3 M lb. Seaplane drag, thrust required, max range velocity for cruise altitude of 20,000 ft.**

**0.3M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure w/o Step**

**Ferry Mission**

| | | |
|---|---|---|
| GTOW | 260,003 | lbf. |
| Empty | 127,244 | lbf. |
| Useful | 132,759 | lbf. |
| Crew | 1,000 | lbf. |
| 5% Reserve | 6,274 | lbf. |
| V | 356.32 | kts. |
| C | 0.468 | lbf./hr/lbf. |
| CD | 0.0298 | lbf. |
| CL | 0.4277 | lbf. |
| L/D | 14.36 | |
| $W_{i-1}$ | 253,971 | lbf. |
| $W_i$ | 136,781 | lbf. |

Definitions

GTOW - Gross Takeoff Weight

Empty - Empty weight

Useful - The difference between GTOW and Empty

V - Velocity in knots (M=0.58) at 20,000 ft.

C - Total Specific Fuel Consumption

$W_{i-1}$ - Initial weight for segment.

$W_i$ - Final weight for segment.

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 6765.3 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 131,759 |
| 1,375 | 90,000 |
| 2,893 | 60,000 |
| 4,657 | 30,000 |
| 6,765 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Altitude | 20,000 | ft | a | 1036.9 | FT/SEC |
| | | | M | 0.58 | |
| | | | V=M*a | 601.402 | FT/SEC |
| C | 0.4679 | | V | 356.32 | KTS |

**Figure 51. Improved Case – 0.3 M lb. Seaplane range vs. payload calculations, with a retracted step.**

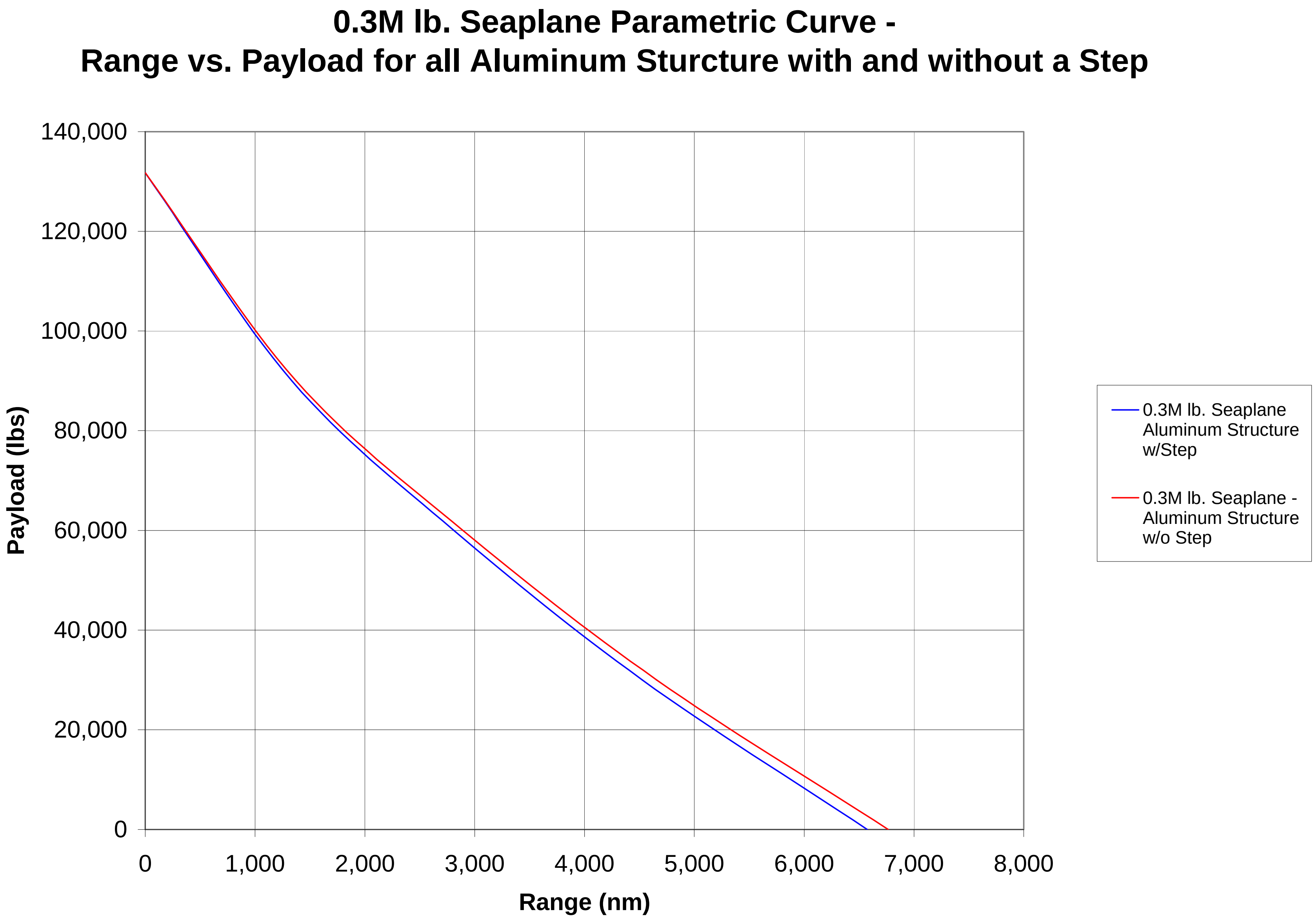



**Figure 52. Improved Case – 0.3 M lb. Seaplane comparison of range vs. payload with a fixed step and with a retracted step.**

### 2.3.3.2 Weight Reduction – Aluminum to Composites

#### *2.3.3.2.1 0.3 M lb. Seaplane: Range vs. Payload for an All Aluminum and an All Composite Structure*

The second performance improvement that was investigated was empty weight reduction through the use of composite materials. The savings were put back into payload to attain the same gross take-off weight (GTOW) as the all aluminum structure seaplane and the two aircraft were compared. For information on the weight saving potential in using composite materials, see Strength of Composites, section 2.3.2.2. Figure 53 shows the calculations for the base aluminum structure seaplane. Figure 54 shows the composite structure with the saved empty weight put toward the useful load. Figure 55 graphically shows the results of the change in structure. The extended range from the all composite structure comes from the ability to translate the empty weight savings into payload, cargo/passengers and fuel. A summary of the results is given below.

0.3 M lb. Seaplane – Range vs. Payload

| | |
|---|---|
| All Composite Structure: | Range = 8,138 nm. |
| All Aluminum Structure: | Range = 6,576 nm. |
| Difference | 1,562 nm. |

**0.3M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure - Base Case**

| **Ferry Mission** | | | Definitions |
|---|---|---|---|
| GTOW | 260,003 | lbf. | GTOW - Gross Takeoff Weight |
| Empty | 127,244 | lbf. | Empty - Empty weight |
| Useful | 132,759 | lbf. | Useful - The difference between GTOW and Empty |
| Crew | 1,000 | lbf. | |
| 5% Reserve | 6,274 | lbf. | |
| V | 356.32 | kts. | V - Velocity in knots (M=0.58) at 20,000 ft. |
| C | 0.468 | lbf./hr/lbf. | C - Total Specific Fuel Consumption |
| CD | 0.0307 | lbf. | |
| CL | 0.4277 | lbf. | |
| L/D | 13.95 | | |
| $W_{i-1}$ | 253,971 | lbf. | $W_{i-1}$ - Initial weight for segment. |
| $W_i$ | 136,781 | lbf. | $W_i$ - Final weight for segment. |

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 6575.6 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 131,759 |
| 1,336 | 90,000 |
| 2,812 | 60,000 |
| 4,526 | 30,000 |
| 6,576 | 0 |

| | | | | |
|---|---|---|---|---|
| Altitude | 20,000 ft | a | 1036.9 | FT/SEC |
| | | M | 0.58 | |
| | | V=M*a | 601.402 | FT/SEC |
| C | 0.4679 | V | 356.32 | KTS |

**Figure 53. Base Case – 0.3 M lb. Seaplane range vs. payload with aluminum structure.**

**0.3M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Composite Structure - Base Case**

**Ferry Mission**

| | | |
|---|---|---|
| GTOW | 260,003 lbf. | GTOW - Gross Takeoff Weight |
| Empty | 107,926 lbf. | Empty - Empty weight |
| Useful | 152,077 lbf. | Useful - The difference between GTOW and Empty |
| Crew | 1,000 lbf. | |
| 5% Reserve | 7,194 lbf. | |
| V | 356.3 kts. | V - Velocity in knots (M=0.58) at 20,000 ft. |
| C | 0.468 lbf./hr/lbf. | C - Total Specific Fuel Consumption |
| CD | 0.0306 lbf. | |
| CL | 0.4277 lbf. | |
| L/D | 13.95 | |
| $W_{i-1}$ | 253,972 lbf. | $W_{i-1}$ - Initial weight for segment. |
| $W_i$ | 118,074 lbf. | $W_i$ - Final weight for segment. |

Definitions (right column above)

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 8138.1 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 151,077 |
| 2,263 | 90,000 |
| 3,883 | 60,000 |
| 5,797 | 30,000 |
| 8,138 | 0 |

| | | | | |
|---|---|---|---|---|
| Altitude | 20,000 ft | a | 1036.9 | FT/SEC |
| | | M | 0.58 | |
| | | V=M*a | 601.402 | FT/SEC |
| C | 0.4679 | V | 356.32 | KTS |

**Figure 54. Improved Case – 0.3 M lb. Seaplane range vs. payload with composite structure.**

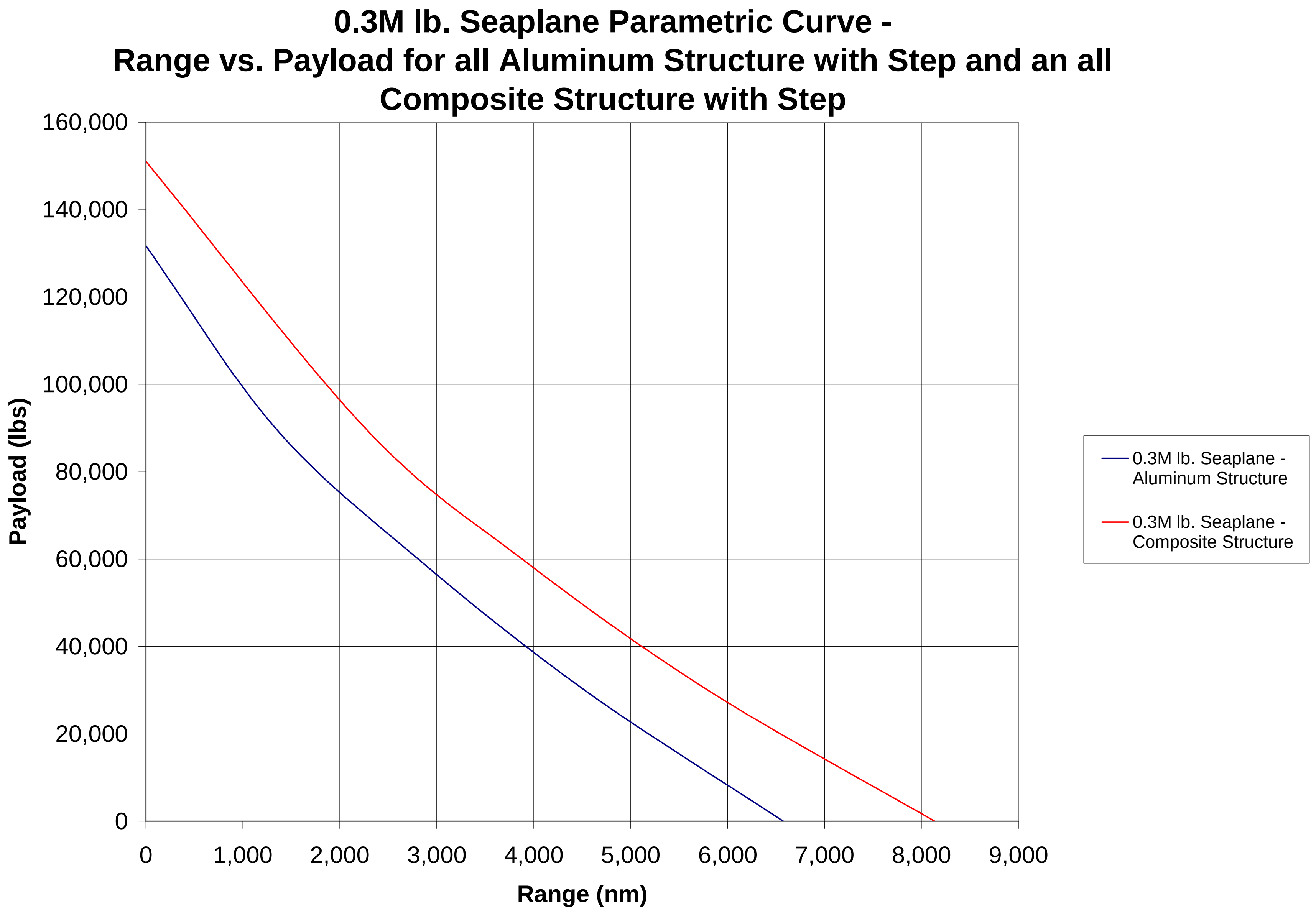



**Figure 55. Improved Case – 0.3 M lb. Seaplane range vs. payload for all aluminum and an all composite structure seaplane.**

## 2.3.4 1.0 M lb. Seaplane Improved

### 2.3.4.1 Drag Reduction

The baseline BFS-1.0 M lb. seaplane has been analyzed for drag, speed, and range, see section 2.2.5 through section 2.2.5.7. The seaplane will again be analyzed for the drag reduction by the use of a retractable step. The drag of the step is calculated in section 2.3.1.1.

The analysis includes the drag breakdown. The drag breakdown has been calculated for M=0.2 to M=0.9 to take into consideration drag rise. This drag includes the step in the hull. The drag will include a step and a hull without a step (retractable). Section 2.3.4.1.5 shows drag tables from M=0.2 to M=0.9 with and without a step.

#### *2.3.4.1.1 Step Drag Calculation*

<u>Drag of Seaplane Step – Method 1</u>
BFS-1.0 M lb.

Ref.: Raymer, Daniel P. *Aircraft Design: A Conceptual Approach, Third Edition*. Reston, Va: American Institute of Aeronautics and Astronautics, Inc., 1999. pg. 350 [8].

Best Range and Speed: M = 0.705, 415.5 kts.

$$\Delta C_D = \frac{C_{D\pi} \cdot S_\pi}{S_w} \qquad f = C_{D\pi} \cdot S_\pi \qquad f = \frac{D}{q}$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.419(M - 0.161)^2\right] \cdot A_{base}$$

---

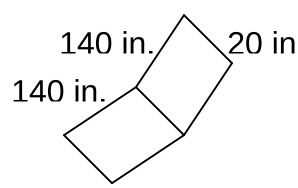
$$S_W = 11{,}362\ ft^2$$

$$M = 0.705$$

$$A = 2 \cdot (20 \cdot 140)$$

$$A = 5600\, in^2$$

$$A = 38.9\ ft^2$$




$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.419(0.705 - 0.161)^2\right] \cdot 38.9\ ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.124\right] \cdot 38.9\ ft^2 \qquad Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.263\right] \cdot 38.9\ ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = 10.23\ ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = 10.23\,ft^2 \qquad f = \frac{D}{q} \qquad f = C_{D\pi} \cdot S_{\pi} \qquad S_W = 11{,}362\,ft^2$$

$$\Delta C_{DStep} = \frac{C_{D\pi} \cdot S_{\pi}}{S_w} \qquad \Delta C_{DStep} = \frac{10.23\,ft^2}{11{,}362\,ft^2} \qquad \boxed{\Delta C_{DStep} = 0.0009004}$$

### *2.3.4.1.2 Drag Table*

The base case BFS-1.0 M lb. seaplane was analyzed in section 2.2.5 for drag, performance, etc. To reduce the drag a retractable step was used during the cruise segment of the mission. Figure 56 below shows the effect of the step on the parasite drag, and the reduction of drag during the cruise segment using the retractable step.

**DRAG BREAKDOWN - COMPONENT METHOD**
**1.0 M lb. Seaplane**

| | M = 0.2 | M = 0.4 | M = 0.6 | M = 0.7 | M = 0.8 | M = 0.9 |
|---|---|---|---|---|---|---|
| **Component** | **Cdo** | **Cdo** | **Cdo** | **Cdo** | **Cdo** | **Cdo** |
| **Body** | 0.00320 | 0.00290 | 0.00277 | 0.00277 | 0.00277 | 0.00277 |
| **Step** | 0.00090 | 0.00090 | 0.00090 | 0.00090 | 0.00090 | 0.00090 |
| **V. Tail** | 0.00121 | 0.00111 | 0.00108 | 0.00114 | 0.00143 | 0.00710 |
| **H. Tail** | 0.00131 | 0.00120 | 0.00117 | 0.00124 | 0.00153 | 0.00670 |
| **Wing** | 0.00590 | 0.00543 | 0.00530 | 0.00560 | 0.00730 | 0.03830 |
| **Pontoons** | 0.00023 | 0.00019 | 0.00017 | 0.00017 | 0.00017 | 0.00017 |
| **Engines** | 0.00140 | 0.00123 | 0.00115 | 0.00115 | 0.00115 | 0.00115 |
| **Engine Mts.** | 0.00020 | 0.00017 | 0.00015 | 0.00015 | 0.00015 | 0.00015 |
| **Cdo** | 0.01435 | 0.01313 | 0.01269 | 0.01312 | 0.01540 | 0.05724 |
| **Pertinences** | X 1.1 | X 1.1 | X 1.1 | X 1.1 | X 1.1 | X 1.1 |
| **Total Cdo** | 0.0157854 | 0.014438 | 0.0139594 | 0.0144324 | 0.0169404 | 0.0629644 |
| **Total Cdo w/o Step** | 0.01480 | 0.01345 | 0.01297 | 0.01344 | 0.01595 | 0.06197 |

**Figure 56. Improved Case – 1.0 M lb. Seaplane parasite drag with a fixed step and with a retracted step**

### 2.3.4.1.3 $C_D$ with a Fixed Step

The total drag for the BFS-1.0 M lb. seaplane with a step at cruise altitude for various mach numbers is shown below in 57. The cruise velocity at an altitude of 30,000 is Mach 0.705.

**1.0M Lb. Seaplane @ 30,000 ft.-STEP**

| Mach | CDi | CDo | $CD_{total}$ |
|---|---|---|---|
| 0.2 | 0.8769 | 0.01579 | 0.89266 |
| 0.4 | 0.0548 | 0.01444 | 0.06924 |
| 0.6 | 0.0108 | 0.01396 | 0.02479 |
| 0.7 | 0.0058 | 0.01443 | 0.02028 |
| 0.8 | 0.0034 | 0.01694 | 0.02037 |
| 0.9 | 0.0021 | 0.06296 | 0.06510 |

**Figure 57. Base Case – 1.0 M lb. Seaplane total drag.**

### 2.3.4.1.4 $C_D$ with a Retracted Step

The total drag for the BFS-1.0 M lb. seaplane without a step at cruise altitude for various mach numbers is shown below in Figure 58 The cruise velocity without a step at an altitude of 30,000 is Mach 0.705

**1.0M Lb. Seaplane @ 30,000 ft.-NO STEP**

| Mach | CDi | CDo | $CD_{total}$ |
|---|---|---|---|
| 0.2 | 0.8769 | 0.01480 | 0.89167 |
| 0.4 | 0.0548 | 0.01345 | 0.06825 |
| 0.6 | 0.0108 | 0.01297 | 0.02379 |
| 0.7 | 0.0058 | 0.01344 | 0.01929 |
| 0.8 | 0.0034 | 0.01595 | 0.01938 |
| 0.9 | 0.0021 | 0.06197 | 0.06411 |

**Figure 58. Improved Case – 1.0 M lb. Seaplane total drag.**

### *2.3.4.1.5 Table – Thrust Required with a Fixed Step and with a Retracted Step*

For the drag calculations for the BFS-1.0 M lb. seaplane with and without a step, see Figure 59 below. Figure 60 illustrates this effect graphically. The maximum cruising speed for the 1.0 M lb. seaplane without a step is M=0.824 or 820 knots, increased from M=0.821 or 817 knots. Thus, the maximum cruise speed attainable increased 3 knots by removing the step. The maximum range cruise velocity for the seaplane without as step was M=0.705, the same as with the step. The L/D ratio for the seaplane increases from 18.99 to 19.97.

**DRAG TABLE W/STEP: 1.0M Lb. Seaplane @ 30,000 ft.**

| Mach | V | ρ | q | 1/q | CL | CL2 | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | slug/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | (W/(S*q))2 | CL2/(pi*AR*e) | | CDo+CDi | Cdtot*q*S |
| 0.2 | 198.96 | 0.000891 | 17.63 | 0.0567 | 4.7458 | 22.5227 | 0.8769 | 0.01579 | 0.8927 | 178,803 |
| 0.4 | 397.92 | 0.000891 | 70.52 | 0.0142 | 1.1865 | 1.4077 | 0.0548 | 0.01444 | 0.0692 | 55,478 |
| 0.6 | 596.88 | 0.000891 | 158.66 | 0.0063 | 0.5273 | 0.2781 | 0.0108 | 0.01396 | 0.0248 | 44,681 |
| 0.7 | 696.36 | 0.000891 | 215.96 | 0.0046 | 0.3874 | 0.1501 | 0.0058 | 0.01443 | 0.0203 | 49,751 |
| 0.8 | 795.84 | 0.000891 | 282.07 | 0.0035 | 0.2966 | 0.0880 | 0.0034 | 0.01694 | 0.0204 | 65,269 |
| 0.9 | 895.32 | 0.000891 | 356.99 | 0.0028 | 0.2344 | 0.0549 | 0.0021 | 0.06296 | 0.0651 | 264,066 |

**DRAG TABLE W/O STEP: 1.0M Lb. Seaplane @ 30,000 ft.**

| Mach | V | ρ | q | 1/q | CL | CL2 | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | lbm/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | (W/(S*q))2 | CL2/(pi*AR*e) | | CDo+CDi | Cdtot*q*S |
| 0.2 | 198.96 | 0.000891 | 17.63 | 0.0567 | 4.7458 | 22.5227 | 0.8769 | 0.01480 | 0.8917 | 178,605 |
| 0.4 | 397.92 | 0.000891 | 70.52 | 0.0142 | 1.1865 | 1.4077 | 0.0548 | 0.01345 | 0.0683 | 54,685 |
| 0.6 | 596.88 | 0.000891 | 158.66 | 0.0063 | 0.5273 | 0.2781 | 0.0108 | 0.01297 | 0.0238 | 42,895 |
| 0.7 | 696.36 | 0.000891 | 215.96 | 0.0046 | 0.3874 | 0.1501 | 0.0058 | 0.01344 | 0.0193 | 47,321 |
| 0.8 | 795.84 | 0.000891 | 282.07 | 0.0035 | 0.2966 | 0.0880 | 0.0034 | 0.01595 | 0.0194 | 62,095 |
| 0.9 | 895.32 | 0.000891 | 356.99 | 0.0028 | 0.2344 | 0.0549 | 0.0021 | 0.06197 | 0.0641 | 260,049 |

**Figure 59. Improved Case – 1.0 M lb. Seaplane thrust required with a fixed step and with a retracted step at a cruise altitude of 30,000 ft.**

### 2.3.4.1.6 Chart – Thrust Required with a Fixed Step and with a Retracted Step

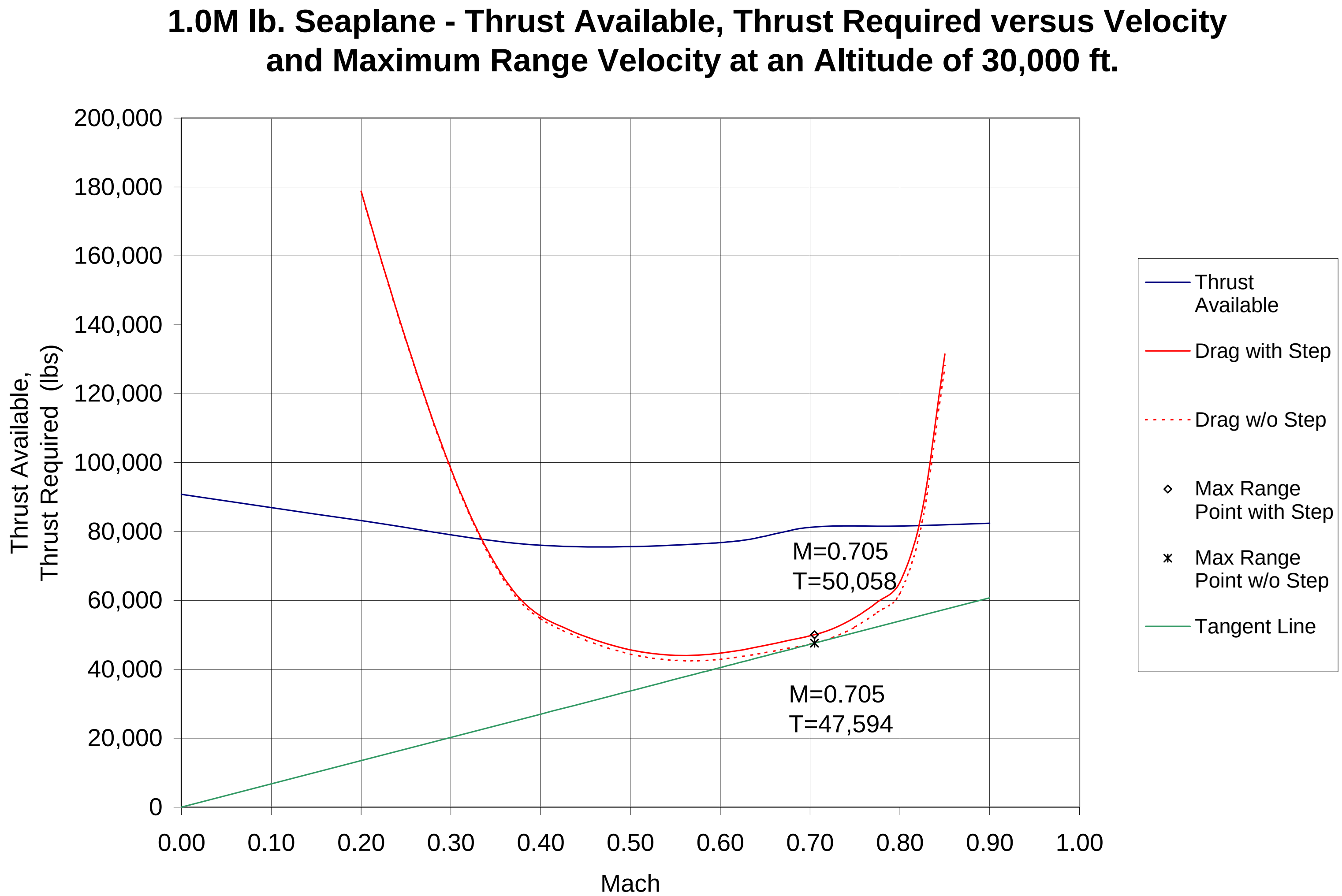



**Figure 60. Improved Case – 1.0 M lb. Seaplane thrust available, thrust required vs. velocity and max range velocity for cruise altitude of 30,000 ft.**

### 2.3.4.1.7 Range vs. Payload with a Fixed Step and with a Retracted Step

The following is a comparison of the range versus payload for the BFS-1.0 M lb. seaplane with and without the step. The range was calculated using the Brequet equation: $R_{cr} = \left(\frac{V}{C}\right) \cdot \left(\frac{L}{D}\right) \cdot \ln\left(\frac{W_{i-1}}{W_i}\right)$. From the previous section entitled "Chart – Thrust Required with a Fixed Step and with a Retracted Step" the velocity at the maximum range and the lift to drag ratio are known. The specific fuel consumption is known through performance curves taken from the engine manufacturer. The change in weight from the beginning segment to the end segment is found from the calibrated Raymer-based weight sizing spreadsheet. The results of the Brequet range equation calculations are shown in Figures 61 and 62. A summary of the range results is given below

| 1.0 M lb. Seaplane | |
|---|---|
| Range without step: | 9,399 nm. |
| Range with step: | 8,936 nm. |
| Difference | 463 nm. |

Thus, the BFS-1.0 M lb. seaplane could extend its range by 463 nm. if it had a retractable step installed. Figure 63 shows this difference graphically.

**1.0M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure - Base Case**

**Ferry Mission**

| | | |
|---|---|---|
| GTOW | 950,600 | lbs. |
| Empty | 470,432 | lbs. |
| Useful | 480,168 | lbs. |
| Crew | 1,800 | lbs. |
| 5% Reserve | 22,779 | lbs. |
| V | 415.53 | kts. |
| C | 0.539 | lbs./hr/lbs. |
| CD | 0.0201 | |
| CL | 0.3825 | |
| L/D | 19.01 | |
| $W_{i-1}$ | 925,725 | lbs. |
| $W_i$ | 503,226 | lbs. |

**Definitions**

Ferry Mission - Start, climb, cruise at best range cruise speed, loiter at sealevel for 30 minutes at optimum speed, and land without any fuel penalty.

GTOW - Gross Takeoff Weight
Empty - Empty weight
Useful - The difference between GTOW and Empty
V - Velocity in knots (M=0.705)
C - Total Specific Fuel Consumption

$W_{i-1}$ - Initial weight for segment (ignoring Climb&Accl.)
$W_i$ - Final weight for segment

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 8,936.2 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 478,368 |
| 1,220 | 360,000 |
| 3,652 | 225,418 |
| 6,351 | 100,000 |
| 8,936 | 0 |

| | | | | |
|---|---|---|---|---|
| Altitude | 30,000 ft | a | 994.8 | FT/SEC |
| | | M | 0.705 | |
| | | V=M*a | 701.334 | FT/SEC |
| C | 0.5388 | V | 415.53 | KTS |

**Figure 61. Base Case – 1.0 M lb. Seaplane range vs. payload calculations.**

**1.0M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure w/o Step**

**Ferry Mission**

| | | |
|---|---|---|
| GTOW | 950,600 | lbs. |
| Empty | 470,432 | lbs. |
| Useful | 480,168 | lbs. |
| Crew | 1,800 | lbs. |
| 5% Reserve | 22,779 | lbs. |
| V | 415.53 | kts. |
| C | 0.539 | lbs./hr/lbs. |
| CD | 0.0191 | |
| CL | 0.3825 | |
| L/D | 20.00 | |
| $W_{i-1}$ | 925,725 | lbs. |
| $W_i$ | 503,226 | lbs. |

**Definitions**

Ferry Mission - Start, climb, cruise at best range cruise speed, loiter at sealevel for 30 minutes at optimum speed, and land without any fuel penalty.

GTOW - Gross Takeoff Weight
Empty - Empty weight
Useful - The difference between GTOW and Empty
V - Velocity in knots (M=0.705)
C - Total Specific Fuel Consumption

$W_{i-1}$ - Initial weight for segment (ignoring Climb&Accl.)
$W_i$ - Final weight for segment

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 9,398.8 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 478,368 |
| 1,283 | 360,000 |
| 3,841 | 225,418 |
| 6,680 | 100,000 |
| 9,399 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Altitude | 30,000 | ft | a | 994.8 | FT/SEC |
| | | | M | 0.705 | |
| | | | V=M*a | 701.334 | FT/SEC |
| C | 0.5388 | | V | 415.53 | KTS |

**Figure 62. Improved Case – 1.0 M lb. Seaplane range vs. payload calculations, with a retracted step**

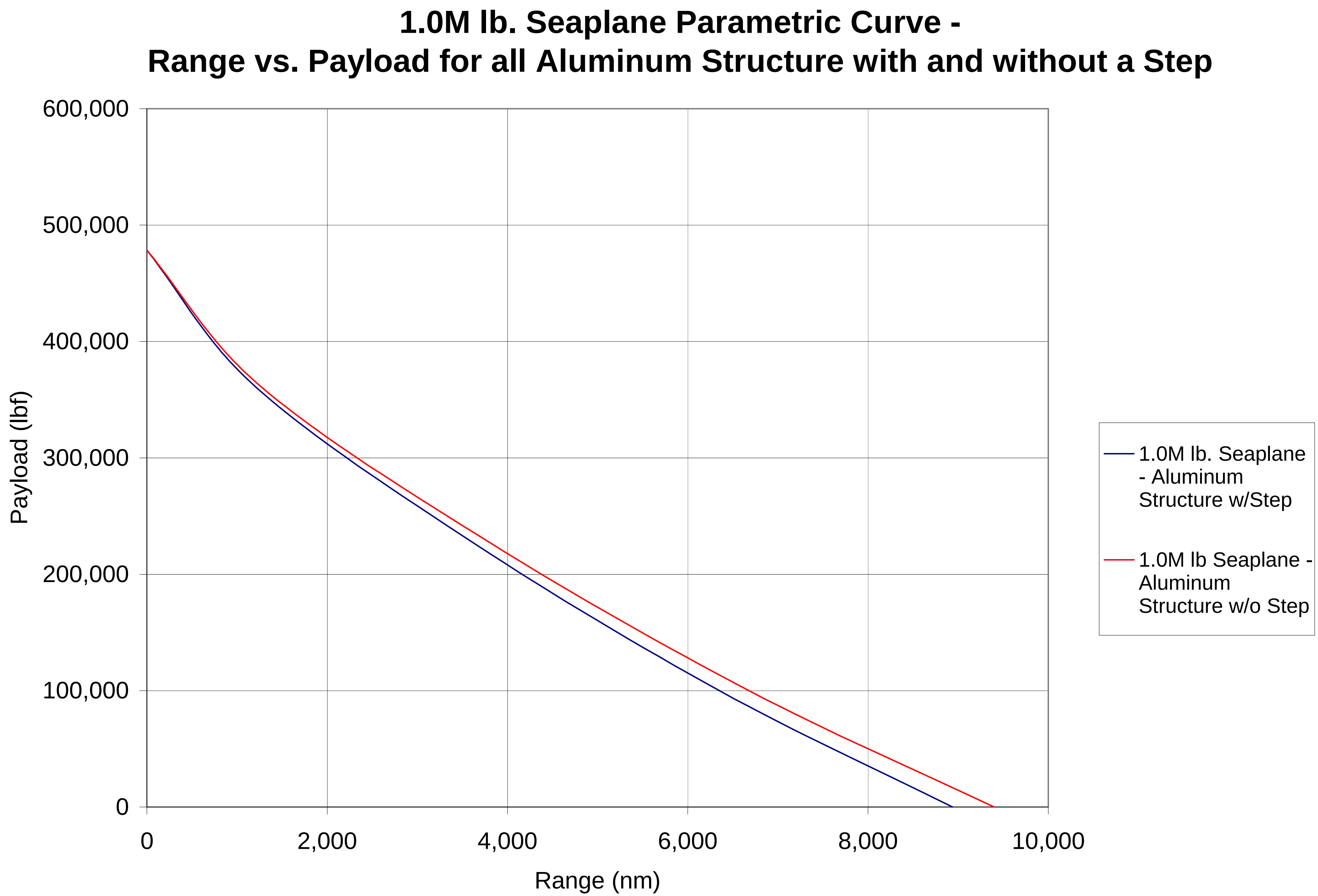



**Figure 63. Improved Case – 1.0 M lb. Seaplane range vs. payload with a fixed step and with a retracted step**

### 2.3.4.2 Weight Reduction – Aluminum to Composites

The second improvement that was investigated was the use of composite materials would save the seaplane structural weight. The savings were put back into payload to attain the same gross take-off weight (GTOW) as the all aluminum structure seaplane. For information on the weight saving potential in using composite materials, see Strength of Composites, section 2.3.2.2. Figure 64 shows the calculations for the base aluminum structure seaplane. Figure 65 shows the composite structure with the saved empty weight put toward the useful load. Figure 66 shows the results of the change in structure graphically. The extended range from the all composite structure comes from the ability to translate the empty weight savings into payload, cargo/passengers and fuel. A summary of the results is given below.

<u>1.0 M lb. Seaplane – Range vs. Payload</u>

| | |
|---|---|
| All Composite Structure: | Range = 11,431 nm. |
| All Aluminum Structure: | Range = 8,936 nm. |
| Difference | 2,495 nm. |

### 2.3.4.2.1 *1.0 M lb. Seaplane: Range vs. Payload for an all Aluminum and an all Composite Structure*

**1.0M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure - Base Case**

**Ferry Mission**

| | | |
|---|---|---|
| GTOW | 950,600 | lbs. |
| Empty | 470,432 | lbs. |
| Useful | 480,168 | lbs. |
| Crew | 1,800 | lbs. |
| 5% Reserve | 22,779 | lbs. |
| V | 415.53 | kts. |
| C | 0.539 | lbs./hr/lbs. |
| CD | 0.0201 | |
| CL | 0.3825 | |
| L/D | 19.01 | |
| $W_{i-1}$ | 925,725 | lbs. |
| $W_i$ | 503,226 | lbs. |

**Definitions**

Ferry Mission - Start, climb, cruise at best range cruise speed, loiter at sealevel for 30 minutes at optimum speed, and land without any fuel penalty.

GTOW - Gross Takeoff Weight
Empty - Empty weight
Useful - The difference between GTOW and Empty
V - Velocity in knots (M=0.705)
C - Total Specific Fuel Consumption

$W_{i-1}$ - Initial weight for segment (ignoring Climb&Accl.)
$W_i$ - Final weight for segment

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 8,936.2 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 478,368 |
| 1,220 | 360,000 |
| 3,652 | 225,418 |
| 6,351 | 100,000 |
| 8,936 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Altitude | 30,000 ft | a | 994.8 | FT/SEC |
| | | M | 0.705 | |
| | | V=M*a | 701.334 | FT/SEC |
| C | 0.5388 | V | 415.53 | KTS |

**Figure 64. Base Case – 1.0 M lb. Seaplane range vs. payload for all aluminum structure**

**1.0M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Composite Structure w/Step**

**Ferry Mission**

| | | |
|---|---|---|
| GTOW | 950,600 | lbs. |
| Empty | 389,099 | lbs. |
| Useful | 561,501 | lbs. |
| Crew | 1,800 | lbs. |
| 5% Reserve | 26,652 | lbs. |
| V | 415.5 | kts. |
| C | 0.539 | lbs./hr/lbs. |
| CD | 0.0201 | |
| CL | 0.3825 | |
| L/D | 19.01 | |
| $W_{i-1}$ | 925,725 | lbs. |
| $W_i$ | 424,481 | lbs. |

**Definitions**

Ferry Mission - Start, climb, cruise at best range cruise speed, loiter at sealevel for 30 minutes at optimum speed, and land without any fuel penalty.

GTOW - Gross Takeoff Weight
Empty - Empty weight
Useful - The difference between GTOW and Empty
V - Velocity in knots (M=0.705)
C - Total Specific Fuel Consumption

$W_{i-1}$ - Initial weight for segment (ignoring Climb&Accl.)
$W_i$ - Final weight for segment

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 11,431.0 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 559,701 |
| 2,641 | 360,000 |
| 5,345 | 225,418 |
| 8,412 | 100,000 |
| 11,431 | 0 |

| | | | | |
|---|---|---|---|---|
| Altitude | 30,000 ft | a | 994.8 | FT/SEC |
| | | M | 0.705 | |
| | | V=M*a | 701.334 | FT/SEC |
| C | 0.5388 | V | 415.53 | KTS |

**Figure 65. Improved Case – 1.0 M lb. Seaplane range vs. payload for all composite structure**

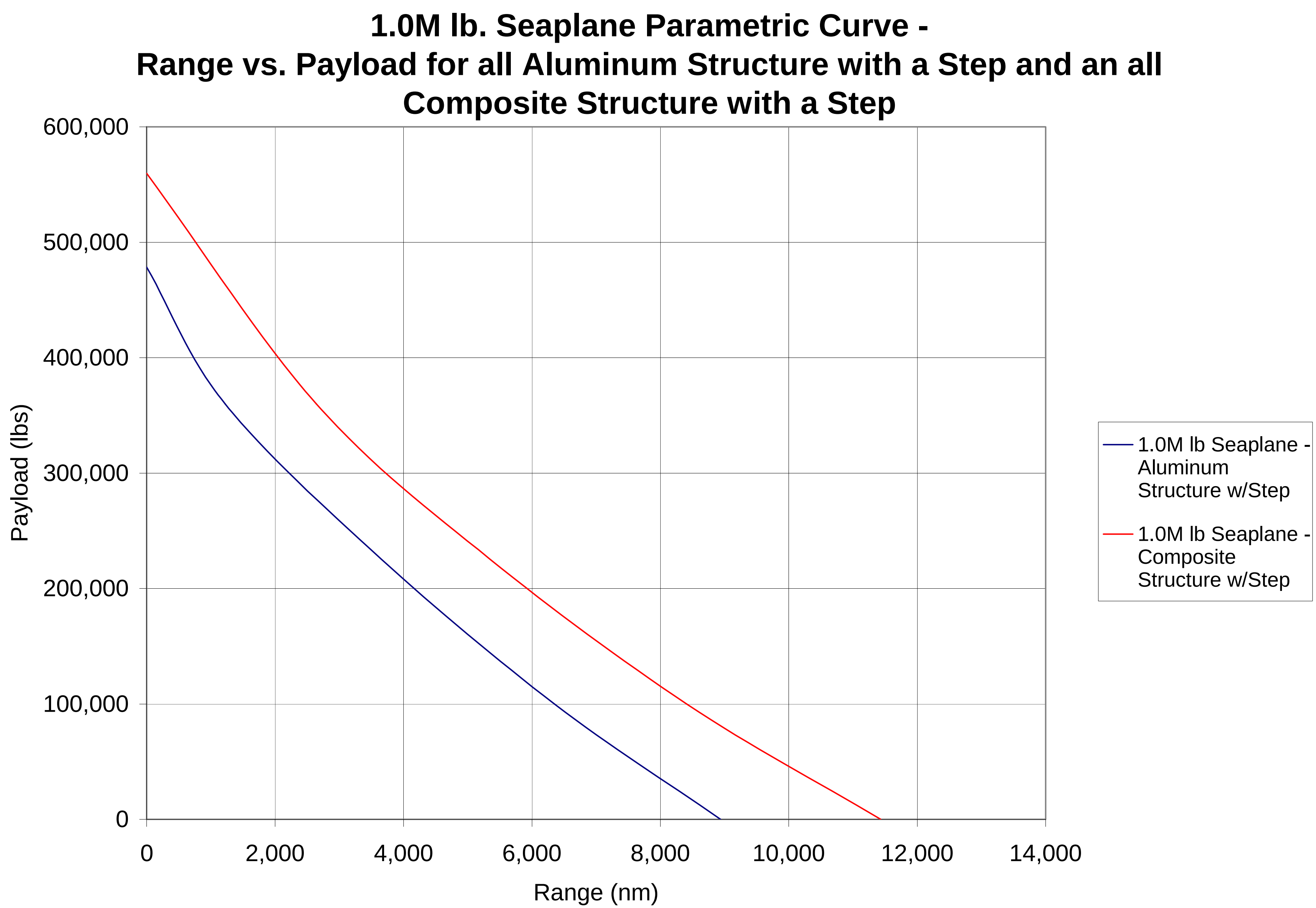



**Figure 66. Improved Case – 1.0 M lb. Seaplane range vs. payload for an all aluminum and all composite structure seaplane.**

## 2.3.5 2.9 M lb. Seaplane Improved

### 2.3.5.1 Drag Reduction

The base case BFS-2.9 M lb. seaplane has been analyzed for drag, speed, and range, see section 2.2.6 through section 2.2.6.7. The seaplane will again be analyzed for the drag reduction by the use of a retractable step. The drag of the step is calculated in section 2.3.1.1.

The analysis includes the drag breakdown. The drag breakdown has been calculated for M=0.2 to M=0.9 to take into consideration drag rise. This drag includes the sep in the hull. The drag will include a step and a hull without a step (retractable). Section 2.3.5.1.5 shows drag tables from M=0.2 to M=0.9 with and without a step.

#### *2.3.5.1.1 Step Drag Calculation*

<u>Drag of Seaplane Step – Method 1</u>
BFS-2.9 M lb.

Ref.: Raymer, Daniel P. *Aircraft Design: A Conceptual Approach, Third Edition*. Reston, Va: American Institute of Aeronautics and Astronautics, Inc., 1999. pg. 350 [8].

Best Range and Speed: M = 0.698, 694 kts.

$$\Delta C_D = \frac{C_{D\pi} \cdot S_\pi}{S_w} \qquad f = C_{D\pi} \cdot S_\pi \qquad f = \frac{D}{q}$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.419(M - 0.161)^2\right] \cdot A_{base}$$

---

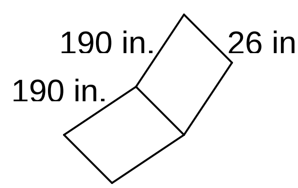
$$S_W = 24{,}135\, ft^2$$

$$M = 0.698$$

$$A = 2 \cdot (26 \cdot 190)$$

$$A = 9880\, in^2$$

$$A = 68.61\, ft^2$$




$$Subsonic\left(\frac{D}{q}\right)_{base} = \left[0.139 + 0.419(0.698 - 0.161)^2\right] \cdot 68.61\, ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = [0.139 + 0.121] \cdot 68.61\, ft^2 \qquad Subsonic\left(\frac{D}{q}\right)_{base} = [0.260] \cdot 68.61\, ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = 17.84\, ft^2$$

$$Subsonic\left(\frac{D}{q}\right)_{base} = 17.84\,ft^2 \qquad f = \frac{D}{q} \qquad f = C_{D\pi} \cdot S_{\pi} \qquad S_W = 24{,}135\,ft^2$$

$$\Delta C_{DStep} = \frac{C_{D\pi} \cdot S_{\pi}}{S_w} \qquad \Delta C_{DStep} = \frac{17.84\,ft^2}{24{,}135\,ft^2} \qquad \boxed{\Delta C_{DStep} = 0.000739}$$

### *2.3.5.1.2 Drag Table*

The base case BFS-2.9 M lb. seaplane was analyzed in section 2.2.6 for drag, performance, etc. To reduce the drag a retractable step was used during the cruise segment of the mission. Figure 67 below shows the effect of the step on the parasite drag, and the reduction of drag during the cruise segment using the retractable step.

**DRAG BREAKDOWN - COMPONENT METHOD**
**2.9 M lb. Seaplane**

| | M = 0.2 | M = 0.4 | M = 0.6 | M = 0.7 | M = 0.8 | M = 0.9 |
|---|---|---|---|---|---|---|
| **Component** | **Cdo** | **Cdo** | **Cdo** | **Cdo** | **Cdo** | **Cdo** |
| **Body** | 0.004150 | 0.003840 | 0.003820 | 0.003540 | 0.003510 | 0.003460 |
| **Step** | 0.000739 | 0.000739 | 0.000739 | 0.000739 | 0.000739 | 0.000739 |
| **V. Tail** | 0.000760 | 0.000677 | 0.000682 | 0.000682 | 0.000700 | 0.000730 |
| **H. Tail** | 0.001250 | 0.001150 | 0.001080 | 0.001080 | 0.001080 | 0.003840 |
| **Wing** | 0.005490 | 0.005080 | 0.004990 | 0.004980 | 0.017930 | 0.044930 |
| **Pontoons** | 0.000473 | 0.000440 | 0.000400 | 0.000380 | 0.000370 | 0.000370 |
| **Engines** | 0.001500 | 0.001300 | 0.001200 | 0.001200 | 0.001200 | 0.001200 |
| **Engine Mts.** | 0.000540 | 0.000520 | 0.000490 | 0.000490 | 0.000506 | 0.000520 |
| **Cdo** | 0.014902 | 0.013746 | 0.013401 | 0.013091 | 0.026035 | 0.055789 |
| **Pertinences** | X 1.1 | X 1.1 | X 1.1 | X 1.1 | X 1.1 | X 1.1 |
| **Total Cdo** | 0.0163922 | 0.0151206 | 0.0147411 | 0.0144001 | 0.0286385 | 0.0613679 |
| **Total Cdo w/o Step** | 0.0155793 | 0.0143077 | 0.0139282 | 0.0135872 | 0.0278256 | 0.060555 |

**Figure 67. Improved Case – 2.9 M lb. Seaplane parasite drag with a fixed step and with a retracted step.**

### *2.3.5.1.3 $C_D$ with a Fixed Step*

The total drag for the BFS-2.9 M lb. seaplane with a step at cruise altitude for various mach numbers is shown below in Figure 68. The cruise velocity at an altitude of 30,000 is Mach 0.698.

**2.9M Lb. Seaplane @ 30,000 ft.-STEP**

| Mach | CDi | CDo | $CD_{total}$ |
|---|---|---|---|
| 0.2 | 1.5712 | 0.01639 | 1.58758 |
| 0.4 | 0.0982 | 0.01512 | 0.11332 |
| 0.6 | 0.0194 | 0.01474 | 0.03414 |
| 0.7 | 0.0105 | 0.01440 | 0.02487 |
| 0.8 | 0.0061 | 0.02864 | 0.03478 |
| 0.9 | 0.0038 | 0.06137 | 0.06520 |

**Figure 68. Base Case – 2.9 M lb. Seaplane total drag.**

### *2.3.5.1.4 $C_D$ with a Retracted Step*

The total drag for the BFS-2.9 M lb. seaplane without a step at cruise altitude for various mach numbers is shown below in Figure 69 The cruise velocity without a step at an altitude of 30,000 is Mach 0.698.

**2.9M Lb. Seaplane @ 30,000 ft.-NO STEP**

| Mach | CDi | CDo | $CD_{total}$ |
|---|---|---|---|
| 0.2 | 1.5712 | 0.01558 | 1.58676 |
| 0.4 | 0.0982 | 0.01431 | 0.11251 |
| 0.6 | 0.0194 | 0.01393 | 0.03333 |
| 0.7 | 0.0105 | 0.01359 | 0.02406 |
| 0.8 | 0.0061 | 0.02783 | 0.03396 |
| 0.9 | 0.0038 | 0.06056 | 0.06439 |

**Figure 69. Improved Case – 2.9 M lb. Seaplane total drag.**

### 2.3.5.1.5 Table – Thrust Required with a Fixed Step and with a Retracted Step

For the drag calculations for the BFS-2.9 M lb. seaplane with and without a step, see Figure 70 below. Figure 71 illustrates this effect graphically. The maximum cruising speed for the 2.9 M lb. seaplane without a step is M=0.782 or 778 knots, which increased from M=0.778 or 774 knots. Thus, the maximum cruising speed attainable increased 4 knots with the removal of the step. The maximum range cruise velocity for the seaplane without as step was M=0.698, the same as with the step. The L/D ratio for the seaplane increases from 22.32 to 23.08.

**DRAG TABLE W/STEP: 2.9M Lb. Seaplane @ 30,000 ft.**

| Mach | V | ρ | q | 1/q | CL | $CL^2$ | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | lbm/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | (W/S*q)^2 | CL^2/(pi*AR*e) | | CDo+CDi | Cdtot*q*S |
| 0.2 | 198.96 | 0.0008907 | 17.63 | 0.0567 | 6.7470 | 45.522611 | 1.571183 | 0.01639 | 1.5876 | 687,798 |
| 0.4 | 397.92 | 0.0008907 | 70.52 | 0.0142 | 1.6868 | 2.845163 | 0.098199 | 0.01512 | 0.1133 | 196,377 |
| 0.6 | 596.88 | 0.0008907 | 158.66 | 0.0063 | 0.7497 | 0.562008 | 0.019397 | 0.01474 | 0.0341 | 133,111 |
| 0.7 | 696.36 | 0.0008907 | 215.96 | 0.0046 | 0.5508 | 0.303358 | 0.010470 | 0.01440 | 0.0249 | 131,991 |
| 0.8 | 795.84 | 0.0008907 | 282.07 | 0.0035 | 0.4217 | 0.177823 | 0.006137 | 0.02864 | 0.0348 | 241,060 |
| 0.9 | 895.32 | 0.0008907 | 356.99 | 0.0028 | 0.3332 | 0.111014 | 0.003832 | 0.06137 | 0.0652 | 571,999 |

**DRAG TABLE W/O STEP: 2.9M Lb. Seaplane @ 30,000 ft.**

| Mach | V | ρ | q | 1/q | CL | $CL^2$ | CDi | CDo | CDtot | Thrust Req. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ft/sec | lbm/ft3 | lbf/ft2 | ft2/lbf | W/(S*q) | (W/S*q)^2 | CL^2/(pi*AR*e) | | CDo+CDi | Cdtot*q*S |
| 0.2 | 198.96 | 0.0008907 | 17.63 | 0.0567 | 6.7470 | 45.522611 | 1.571183 | 0.01558 | 1.5868 | 687,446 |
| 0.4 | 397.92 | 0.0008907 | 70.52 | 0.0142 | 1.6868 | 2.845163 | 0.098199 | 0.01431 | 0.1125 | 194,969 |
| 0.6 | 596.88 | 0.0008907 | 158.66 | 0.0063 | 0.7497 | 0.562008 | 0.019397 | 0.01393 | 0.0333 | 129,941 |
| 0.7 | 696.36 | 0.0008907 | 215.96 | 0.0046 | 0.5508 | 0.303358 | 0.010470 | 0.01359 | 0.0241 | 127,677 |
| 0.8 | 795.84 | 0.0008907 | 282.07 | 0.0035 | 0.4217 | 0.177823 | 0.006137 | 0.02783 | 0.0340 | 235,425 |
| 0.9 | 895.32 | 0.0008907 | 356.99 | 0.0028 | 0.3332 | 0.111014 | 0.003832 | 0.06056 | 0.0644 | 564,868 |

**Figure 70. Improved Case – 2.9 M lb. Seaplane thrust required with a fixed step and with a retracted step at a cruise altitude of 30,000 ft.**

### *2.3.5.1.6 Chart – Thrust Required with a Fixed Step and with a Retracted Step*

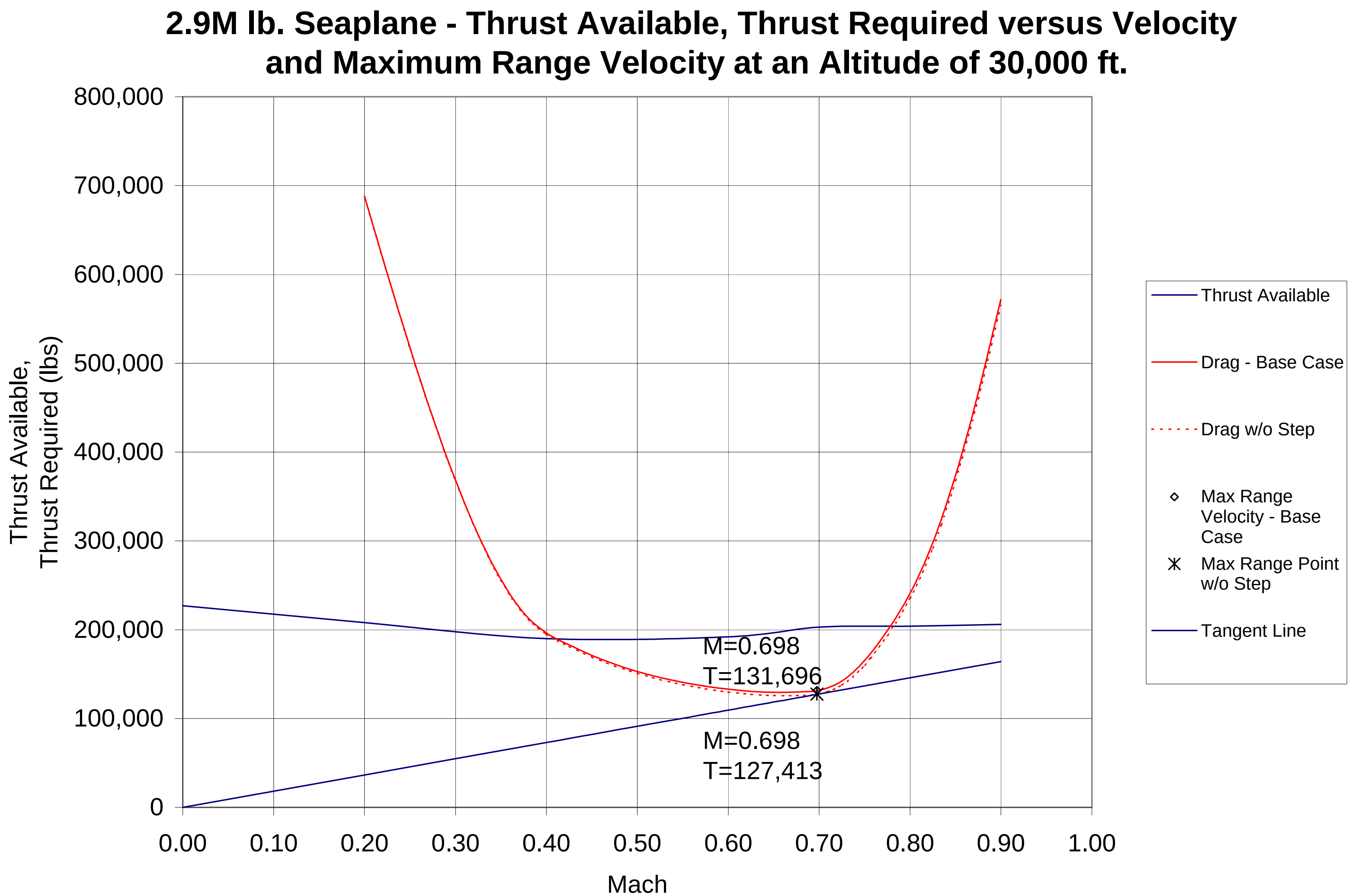



**Figure 71. Improved Case – 2.9 M lb. Seaplane thrust required, thrust available vs. velocity and max range velocity with a fixed step and with a retracted step.**

### *2.3.5.1.7 Range vs. Payload with a Fixed Step and with a Retracted Step*

The following is a comparison of the range versus payload for the 2.9 M lb. seaplane with and without the step. The range was calculated using the Brequet equation: $R_{cr} = \left(\frac{V}{C}\right)\cdot\left(\frac{L}{D}\right)\cdot\ln\left(\frac{W_{i-1}}{W_i}\right)$. From the previous section entitled "Chart – Thrust Required with a Fixed Step and with a Retracted Step" the velocity at the maximum range and the lift to drag ratio are known. The specific fuel consumption is known through performance curves taken from the engine manufacturer. The change in weight from the beginning segment to the end segment is found from the calibrated Raymer-based weight sizing spreadsheet. The results of the Brequet range equation calculations are shown in Figures 72 and 73. A summary of the range results is given below.

| 2.9 M lb. Seaplane | |
|---|---|
| Range without step: | 11,018 nm. |
| Range with step: | 10,601 nm. |
| Difference | 417 nm. |

Thus, the BFS-2.9 M lb. seaplane could extend its range by 417 nm. if it had a retractable step installed. Figure 74 shows this difference graphically.

**2.9M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure - Base Case**

| **Ferry Mission** | | | **Definitions** |
|---|---|---|---|
| GTOW | 2,923,076 | lbs. | GTOW - Gross Takeoff Weight |
| Empty | 1,430,076 | lbs. | Empty - Empty weight |
| Useful | 1,493,000 | lbs. | Useful - The difference between GTOW and Empty |
| Crew | 1,800 | lbs. | |
| 5% Reserve | 71,010 | lbs. | Payload - Crew and 5% fuel reserve subtracted from the useful load |
| V | 411 | kts. | V - Velocity in knots (M=0.6975) |
| C | 0.54 | lbs./hr/lbs. | C - Specific Fuel Consumption |
| CD | 0.025 | | |
| CL | 0.554 | | |
| L/D | 22.21 | | |
| $W_{i-1}$ | 2,842,687 | lbs. | $W_{i-1}$ - Initial weight for segment |
| $W_i$ | 1,524,783 | lbs. | $W_i$ - Final weight for segment |

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 10,600.9 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 1,491,200 |
| 2,246 | 1,000,000 |
| 5,912 | 500,000 |
| 8,092 | 250,000 |
| 10,601 | 0 |

| | | | |
|---|---|---|---|
| Altitude | 30,000 ft | a | 994.8 FT/SEC |
| | | M | 0.6975 |
| | | V=M*a | 693.87 FT/SEC |
| C | 0.5364 | V | 411.11 KTS |

**Figure 72. Base Case – 2.9 M lb. Seaplane range vs. payload.**

**2.9M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure w/oStep**

| **Ferry Mission** | | | **Definitions** |
|---|---|---|---|
| GTOW | 2,923,076 | lbs. | GTOW - Gross Takeoff Weight |
| Empty | 1,430,076 | lbs. | Empty - Empty weight |
| Useful | 1,493,000 | lbs. | Useful - The difference between GTOW and Empty |
| Crew | 1,800 | lbs. | |
| 5% Reserve | 71,010 | lbs. | Payload - Crew and 5% fuel reserve subtracted from the useful load |
| V | 411 | kts. | V - Velocity in knots (M=0.6975) |
| C | 0.54 | lbf./hr/lbf. | C - Specific Fuel Consumption |
| CD | 0.024 | | |
| CL | 0.554 | | |
| L/D | 23.080 | | |
| $W_{i-1}$ | 2,842,687 | lbs. | $W_{i-1}$ - Initial weight for segment |
| $W_i$ | 1,524,783 | lbs. | $W_i$ - Final weight for segment |

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 11,018.5 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 1,491,200 |
| 2,334 | 1,000,000 |
| 6,145 | 500,000 |
| 8,411 | 250,000 |
| 11,018 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Altitude | 30,000 | ft | a | 994.8 | FT/SEC |
| | | | M | 0.6975 | |
| | | | V=M*a | 693.87 | FT/SEC |
| C | 0.5364 | | V | 411.11 | KTS |

**Figure 73. Improved Case – 2.9 M lb. Seaplane range vs. payload, with a retracted step.**

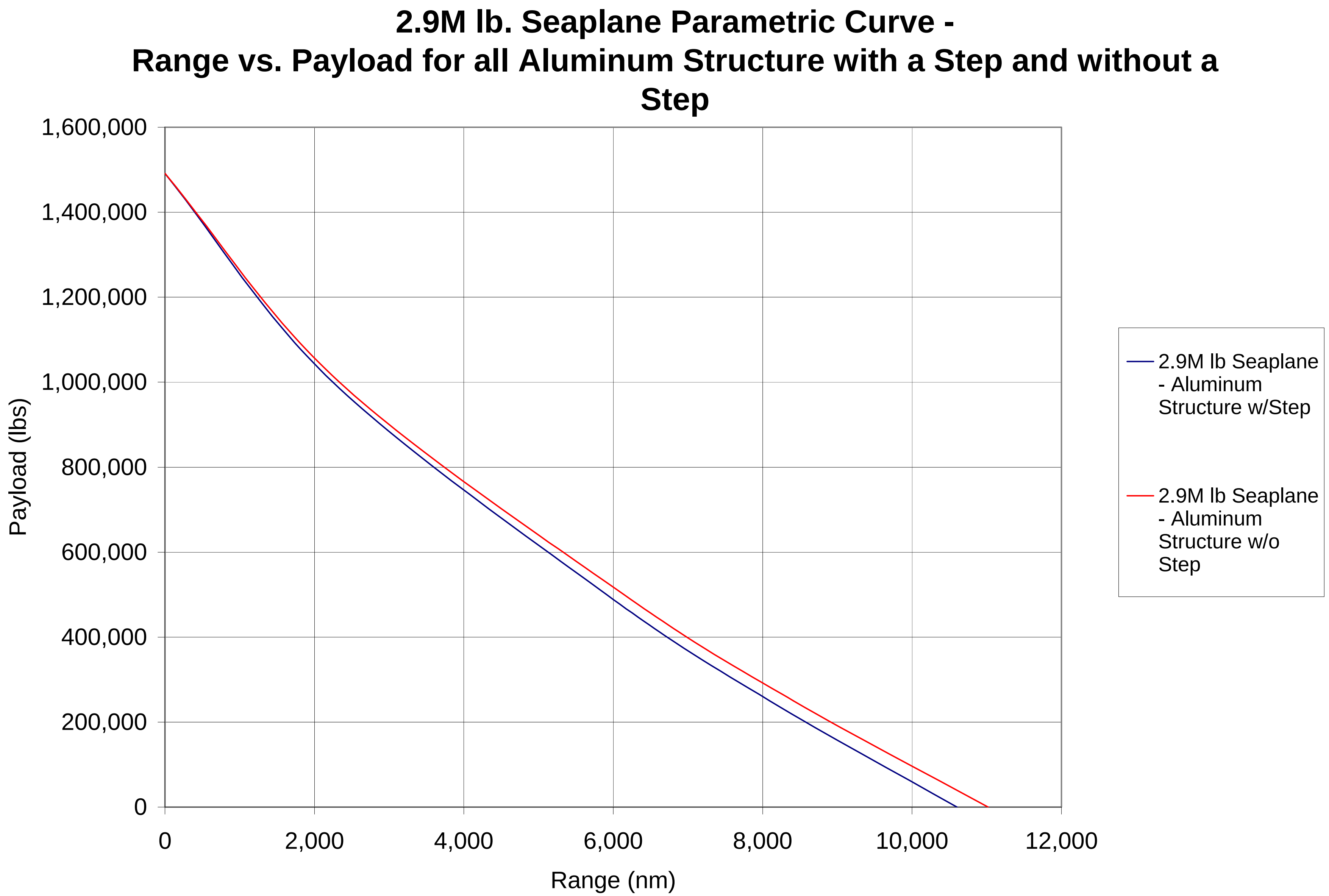



**Figure 74. Improved Case – 2.9 M lb. Seaplane range vs. payload with a fixed step and with a retracted step.**

### 2.3.5.2 Weight Reduction – Aluminum to Composites

#### *2.3.5.2.1 2.9 M lb. Seaplane: Range vs. Payload for an all Aluminum and an all Composite Structure*

The second improvement that was investigated was the use of composite materials to reduce the seaplane structural weight. The savings were put back into payload to attain the same gross take-off weight (GTOW) as the all aluminum structure seaplane. For information on the weight saving potential in using composite materials, see Strength of Composites, section 2.3.2.2. Figure 75 shows the calculations for the base aluminum structure seaplane. Figure 76 shows the composite structure with the saved empty weight put toward the useful load. Figure 77 shows the results of the change in structure graphically. The extended range from the all composite structure comes from the ability to translate the empty weight savings into payload, cargo/passengers and fuel. A summary of the results is given below.

2.9 M lb. Seaplane – Range vs. Payload

| | |
|---|---|
| All Composite Structure: | Range = 13,897 nm. |
| All Aluminum Structure: | Range = 10,601 nm. |
| Difference | 3,296 nm. |

**2.9M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Aluminum Structure - Base Case**

| **Ferry Mission** | | | **Definitions** |
|---|---|---|---|
| GTOW | 2,923,076 | lbs. | GTOW - Gross Takeoff Weight |
| Empty | 1,430,076 | lbs. | Empty - Empty weight |
| Useful | 1,493,000 | lbs. | Useful - The difference between GTOW and Empty |
| Crew | 1,800 | lbs. | |
| 5% Reserve | 71,010 | lbs. | Payload - Crew and 5% fuel reserve subtracted from the useful load |
| V | 411 | kts. | V - Velocity in knots (M=0.6975) |
| C | 0.54 | lbs./hr/lbs. | C - Specific Fuel Consumption |
| CD | 0.025 | | |
| CL | 0.554 | | |
| L/D | 22.21 | | |
| $W_{i-1}$ | 2,842,687 | lbs. | $W_{i-1}$ - Initial weight for segment |
| $W_i$ | 1,524,783 | lbs. | $W_i$ - Final weight for segment |

**Brequet Range Equation**

$$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$$

$R_{cr}$ = 10,600.9 nm.

**Range vs. Payload**

| Range | Payload |
|---|---|
| 0 | 1,491,200 |
| 2,246 | 1,000,000 |
| 5,912 | 500,000 |
| 8,092 | 250,000 |
| 10,601 | 0 |

| | | | |
|---|---|---|---|
| Altitude | 30,000 ft | a | 994.8 FT/SEC |
| | | M | 0.6975 |
| | | V=M*a | 693.87 FT/SEC |
| C | 0.5364 | V | 411.11 KTS |

**Figure 75. Base Case – 2.9 M lb. Seaplane range vs. payload calculations with aluminum structure.**

**2.9M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. Payload for **Composite Structure w/Step**

| **Ferry Mission** | | | **Definitions** |
|---|---|---|---|
| GTOW | 2,923,076 | lbs. | GTOW - Gross Takeoff Weight |
| Empty | 1,152,204 | lbs. | Empty - Empty weight |
| Useful | 1,770,872 | lbs. | Useful - The difference between GTOW and Empty |
| Crew | 1,800 | lbs. | |
| 5% Reserve | 84,242 | lbs. | |
| V | 411 | kts. | V - Velocity in knots (M=0.693) |
| C | 0.54 | lbf./hr/lbf. | C - Specific Fuel Consumption |
| CD | 0.0250 | | Payload - Crew and 5% fuel reserve subtracted from the useful load |
| CL | 0.5543 | | |
| L/D | 22.21 | | |
| $W_{i-1}$ | 2,842,687 | lbs. | $W_{i-1}$ - Initial weight for segment (ignoring Climb&Accl.) |
| $W_i$ | 1,256,287 | lbs. | $W_i$ - Final weight for segment |

**Brequet Range Equation**

$R_{cr} = (V/C)*(L/D)*\ln(W_{i-1}/W_i)$

$R_{cr}$ = 13,897.3 nm.

**Range vs. Pay. w/Composite Struct.**

| Range | Payload |
|---|---|
| 0 | 1,769,072 |
| 4,185 | 1,000,000 |
| 8,353 | 500,000 |
| 10,896 | 250,000 |
| 13,897 | 0 |

| | | | | |
|---|---|---|---|---|
| Altitude | 30,000 ft | a | 994.8 | FT/SEC |
| | | M | 0.6975 | |
| | | V=M*a | 693.87 | FT/SEC |
| C | 0.5364 | V | 411.11 | KTS |

**Figure 76. Improved Case – 2.9 M lb. Seaplane range vs. payload calculations with composite structure.**

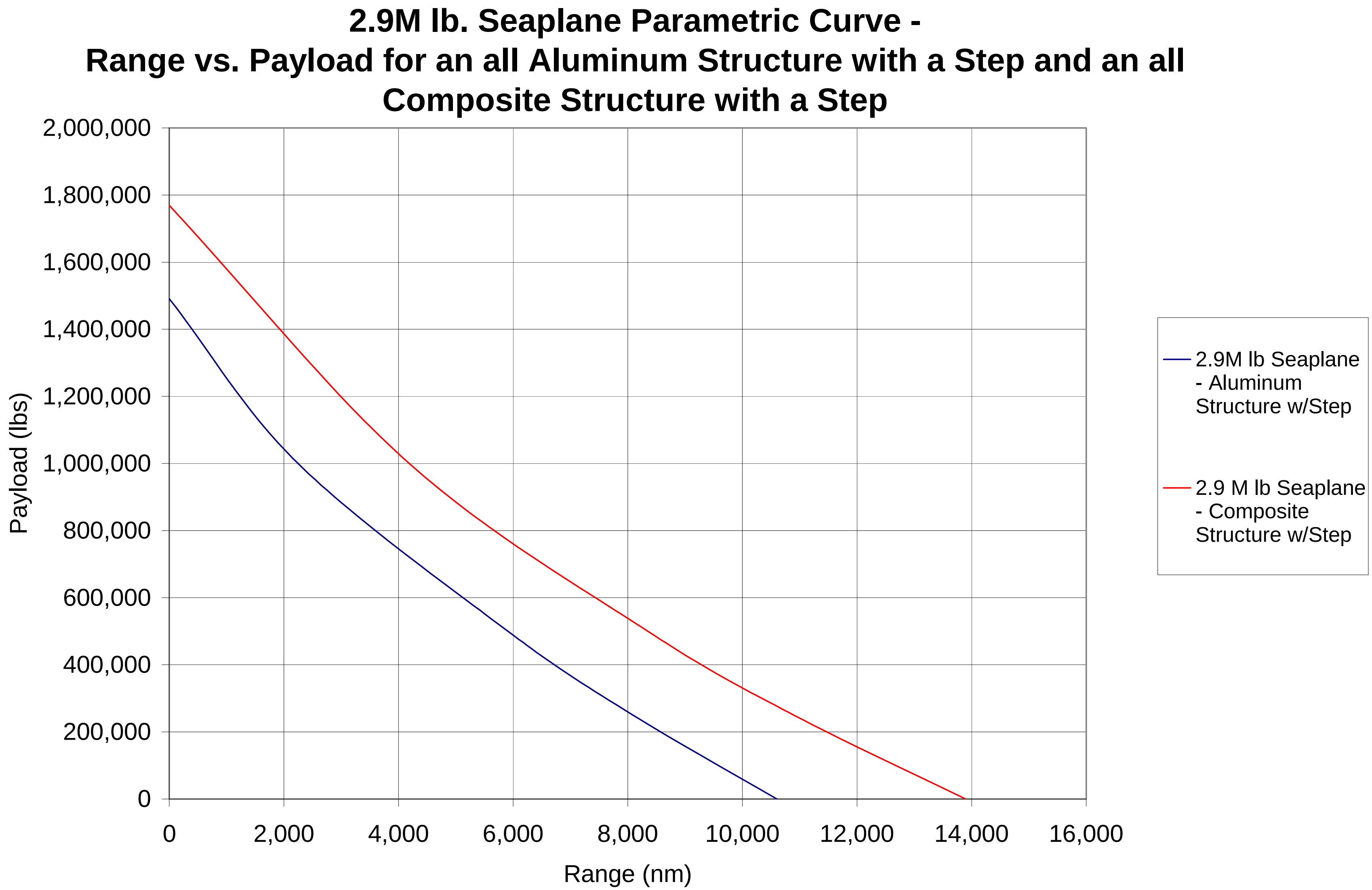



**Figure 77. Improved Case – 2.9 M lb. Seaplane range vs. payload for an all aluminum and all composite structure.**

# 3.0 TRADE STUDIES – 1.0 M LB. SEAPLANE, EFFECTS ON GROSS TAKE-OFF WEIGHT

Up to this point, the three basic seaplanes have been discussed along with how the various improvements affect each seaplane's performance. However, with the basic data contained in this report for a fairly fixed design, a trade study can be performed.

The trade study is important for military planners and other customers who may not be satisfied with a specific range proposed and would want to see what would happen to the design if a larger range or payload was specified.

Using the calibrated base case for the 1.0 M lb. seaplane, two trade studies were performed. The first study investigated the effect of range variation on gross take-off weight (GTOW) with the base design payload held constant. The second study investigated the effect of design payload on gross take-off weight if the base designed range was fixed. The trade studies were performed using the aircraft sizing spreadsheet; see section 2.2.2.1 for details.

## 3.1 TRADE STUDY 1. 1.0 M LB. SEAPLANE: RANGE VS. GTOW

The effect on gross take-off weight when increasing or decreasing the range was studied first using the BFS-1.0 M lb. seaplane. This study used a constant payload of 360,000 lb. As expected, when the range is decreased from the base range of 1,222 nm. the GTOW decreases, and when the range is increased from the base range of 1,222 nm. the GTOW increases. This trade study was done for the all aluminum structure seaplane and the all composite structure seaplane. A summary of the results is given in Figures 78 and 79. A graphical view of the results is given in Figure 80.

The average change in gross take-off weight per nautical mile from the base case is 67.60 lbs./nm. This equates to approximately 68 lbs. added to the gross take-off weight for each additional nautical mile that is traveled beyond the base range.

The average change in gross take-off weight per nautical mile for the composite structure seaplane is 62.87 lbs./nm. This ratio shows that approximately 63 lbs. must be added to the gross take-off weight for each additional nautical mile traveled beyond the base range.

**1.0M lb. SEAPLANE**

PARAMETRIC CURVE - Range vs. GTOW for **Base Case** - **Aluminum Structure**

**Designed Seaplane**

| | |
|---|---|
| GTOW | 950,600 lbs. |
| Payload | 360,000 lbs |
| Range | 1,220 nm |

**Case 1**

| | |
|---|---|
| GTOW | 903,684 lbs. |
| Range | 500 nm |

**Case 2**

| | |
|---|---|
| GTOW | 936,226 lbs. |
| Range | 1,000 nm |

**Case 3**

| | |
|---|---|
| GTOW | 1,002,233 lbs. |
| Range | 2,000 nm |

**Case 4**

| | |
|---|---|
| GTOW | 1,070,140 lbs. |
| Range | 3,000 nm |

**Case 5**

| | |
|---|---|
| GTOW | 1,214,922 lbs. |
| Range | 5,000 nm |

**Case 5**

| | |
|---|---|
| GTOW | 1,293,783 lbs. |
| Range | 6,000 nm |

**Comments**

All cases have the same payload weight of 360,000 lbs.

Each case transports the payload at a different range, which will alter the gross takeoff weight (GTOW).

The results of the GTOW growth and shrink are shown on the chart.

Payload includes passengers, cargo, unuseable fuel, oil, tiedown devices, restraint gates, survival equipment for the air crew, pallets, and pallet nets.

**Aluminum Structure**

**RANGE VS. GTOW SUMMARY**

| Range (nm) | GTOW (lbs) |
|---|---|
| 500 | 903,684 |
| 1,000 | 936,226 |
| 1,220 | 950,600 |
| 2,000 | 1,002,233 |
| 3,000 | 1,070,140 |
| 5,000 | 1,214,922 |
| 6,000 | 1,293,783 |

**Figure 78. 1.0 M lb Seaplane with an all aluminum structure range vs. GTOW**

**1.0M lb. SEAPLANE**
PARAMETRIC CURVE - Range vs. GTOW for **Composite Structure**

**Designed Seaplane**

| | | |
|---|---|---|
| GTOW | 862,037 | lbs. |
| Payload | 360,000 | lbs. |
| Range | 1,220 | nm |

**Case 1**

| | | |
|---|---|---|
| GTOW | 817,786 | lbs. |
| Range | 500 | nm |

**Case 2**

| | | |
|---|---|---|
| GTOW | 848,520 | lbs. |
| Range | 1,000 | nm |

**Case 3**

| | | |
|---|---|---|
| GTOW | 910,413 | lbs. |
| Range | 2,000 | nm |

**Case 4**

| | | |
|---|---|---|
| GTOW | 973,449 | lbs. |
| Range | 3,000 | nm |

**Case 5**

| | | |
|---|---|---|
| GTOW | 1,103,662 | lbs. |
| Range | 5,000 | nm |

**Case 5**

| | | |
|---|---|---|
| GTOW | 1,176,587 | lbs. |
| Range | 6,000 | nm |

**Comments**

All cases have the same payload weight of 360,000 lbs.

Each case transports the payload at a different range, which will alter the gross takeoff weight (GTOW).

The results of the GTOW growth and shrink are shown on the chart.

Payload includes passengers, cargo, unuseable fuel, oil, tiedown devices, restraint gates, survival equipment for the air crew, pallets, and pallet nets.

**Composite Structure**
**RANGE VS. GTOW SUMMARY**

| Range (nm) | GTOW (lbs) |
|---|---|
| 500 | 817,786 |
| 1,000 | 848,520 |
| 1,220 | 862,037 |
| 2,000 | 910,413 |
| 3,000 | 973,449 |
| 5,000 | 1,103,662 |
| 6,000 | 1,176,587 |

**Figure 79. 1.0 M lb Seaplane with an all composite structure range vs. GTOW**

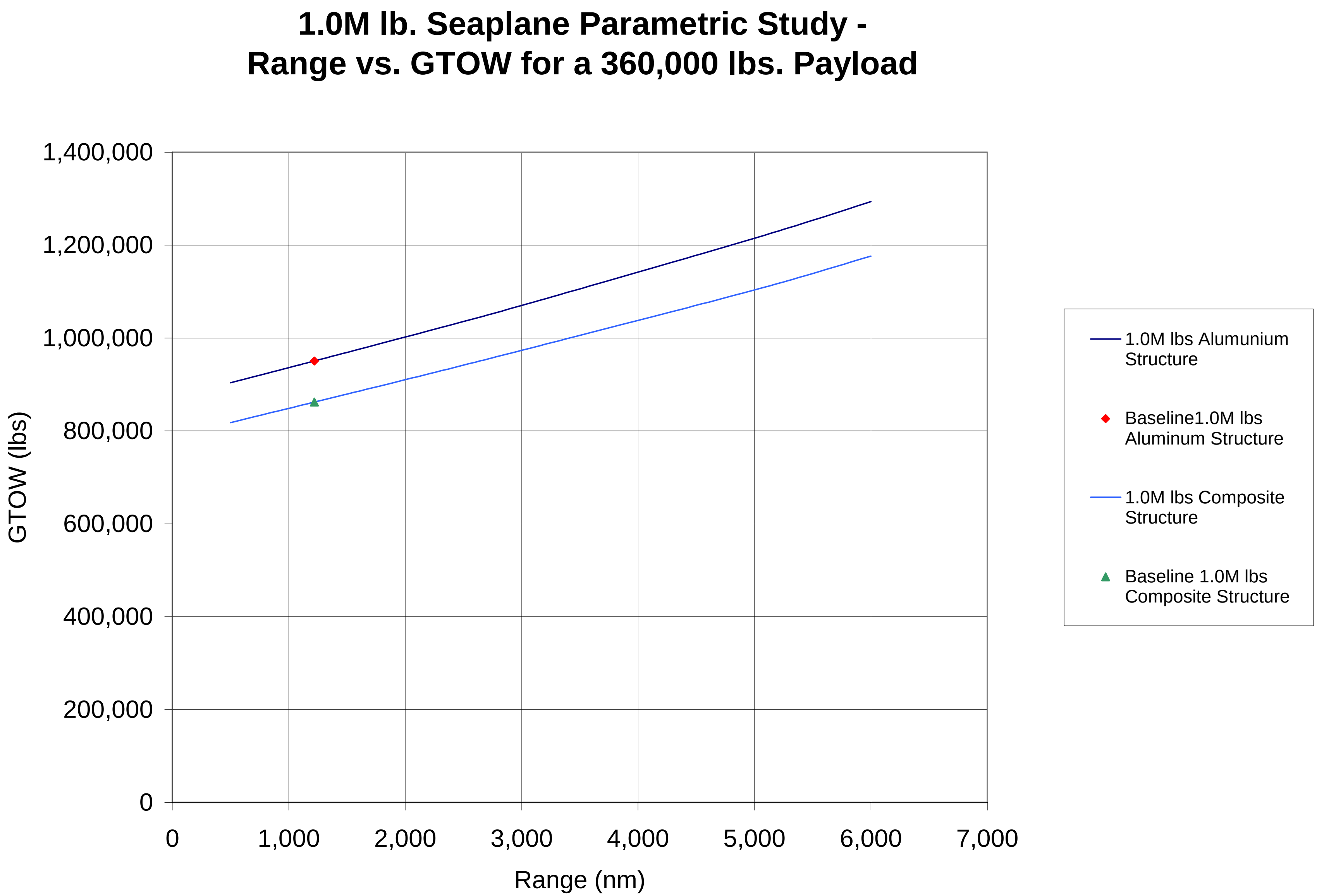



**Figure 80. 1.0 M lb. Seaplane with an all aluminum and all composite structure: Range vs. GTOW**

### 3.2 TRADE STUDY 2. 1.0 M LB. SEAPLANE: PAYLOAD VS. GTOW

The effect on gross take-off weight when increasing or decreasing the payload was studied second for the BFS-1.0 M lb. seaplane. The range is fixed at the base range of 1,222 nm. The base case specifications for the BFS-1.0 M lb. seaplane are as follows:

<u>BFS-1.0 M lb. Seaplane – Base Case</u>

GTOW: 950,000 lbs.
Payload: 360,000 lbs.
Range: 1,220 nm.

Six different payload cases were investigated. Payloads ranged from 100,000 lbs. to 700,000 lbs. The output is a new gross take-off weight. As expected, when the payload is decreased from the base weight of 360,000 lbs. the GTOW decreases, and when the payload is increased from the base weight of 360,000 lbs. the GTOW increases. This trade study was done for the all aluminum structure seaplane and the all composite structure seaplane. A summary of the results is given in Figures 81 and 82. A graphical view of the results is given in Figure 83.

The average change in gross take-off weight per pound of payload from the base case is 1.10 lbs./lbs. This equates to approximately 1.1 lbs. added to the gross take-off weight for each additional pound of payload that is carried beyond the base payload.

The average change in gross take-off weight per pound of payload for the composite structure seaplane is 1.09 lbs./lbs. This ratio shows that approximately 1.09 lbs. must be added to the gross take-off weight for each additional pound of payload that is carried beyond the base payload.

**1.0M lb. SEAPLANE**
PARAMETRIC CURVE - Payload vs. GTOW for **Base Case - Aluminum Structure**

**Designed Seaplane**

| | | |
|---|---|---|
| GTOW | 950,600 | lbs |
| Payload | 360,000 | lbs |
| Range | 1,220 | nm |

**Case 1**

| | | |
|---|---|---|
| GTOW | 669,174 | lbs |
| Payload | 100,000 | lbs |

**Case 2**

| | | |
|---|---|---|
| GTOW | 796,876 | lbs |
| Payload | 225,418 | lbs |

**Case 3**

| | | |
|---|---|---|
| GTOW | 994,341 | lbs |
| Payload | 400,000 | lbs |

**Case 4**

| | | |
|---|---|---|
| GTOW | 1,104,447 | lbs |
| Payload | 500,000 | lbs |

**Case 5**

| | | |
|---|---|---|
| GTOW | 1,215,265 | lbs |
| Payload | 600,000 | lbs |

**Case 6**

| | | |
|---|---|---|
| GTOW | 1,327,232 | lbs |
| Payload | 700,000 | lbs |

**Comments**

All cases have the same range of 1,222 nm.

Each case transports a different payload weight at the designed range, which will alter the gross takeoff weight (GTOW).

The results of the GTOW growth and shrink are shown on the chart.

Payload includes passengers, cargo, unuseable fuel, oil, tiedown devices, restraint gates, survival equipment for the air crew, pallets, and pallet nets.

Case 2 represents the max cargo load at 2.5g that the C-5B would typically carry.

**Aluminum Structure**
**PAYLOAD VS. GTOW SUMMARY**

| Payload (lbf) | GTOW (lbs.) |
|---|---|
| 100,000 | 669,174 |
| 225,418 | 796,876 |
| 360,000 | 950,600 |
| 400,000 | 994,341 |
| 500,000 | 1,104,447 |
| 600,000 | 1,215,265 |
| 700,000 | 1,327,232 |

**Figure 81. 1.0 M lb Seaplane with an all aluminum structure Payload vs. GTOW**

**1.0M lb. SEAPLANE**

PARAMETRIC CURVE - Payload vs. GTOW for **Composite Structure**

**Designed Seaplane**

| | | |
|---|---|---|
| GTOW | 862,045 | lbs |
| Payload | 360,000 | lbs |
| Range | 1,220 | nm |

**Case 1**

| | | |
|---|---|---|
| GTOW | 582,175 | lbs |
| Payload | 100,000 | lbs |

**Case 2**

| | | |
|---|---|---|
| GTOW | 716,614 | lbs |
| Payload | 225,418 | lbs |

**Case 3**

| | | |
|---|---|---|
| GTOW | 905,527 | lbs |
| Payload | 400,000 | lbs |

**Case 4**

| | | |
|---|---|---|
| GTOW | 1,014,801 | lbs |
| Payload | 500,000 | lbs |

**Case 5**

| | | |
|---|---|---|
| GTOW | 1,124,948 | lbs |
| Payload | 600,000 | lbs |

**Case 6**

| | | |
|---|---|---|
| GTOW | 1,236,065 | lbs |
| Payload | 700,000 | lbs |

**Comments**

All cases have the same range of 1222 nm.

Each case transports a different payload weight at the designed range, which will alter the gross takeoff weight (GTOW).

The results of the GTOW growth and shrink are shown on the chart.

Payload includes passengers, cargo, unuseable fuel, oil, tiedown devices, restraint gates, survival equipment for the air crew, pallets, and pallet nets.

Case 2 represents the max cargo load at 2.5g that the C-5B would typically carry.

**Composite Structure**

**PAYLOAD VS. GTOW SUMMARY**

| Payload (lbf) | GTOW (lbf) |
|---|---|
| 100,000 | 582,175 |
| 225,418 | 716,614 |
| 360,000 | 862,045 |
| 400,000 | 905,527 |
| 500,000 | 1,014,801 |
| 600,000 | 1,124,948 |
| 700,000 | 1,236,065 |

**Figure 82. 1.0 M lb Seaplane with an all aluminum structure Payload vs. GTOW**

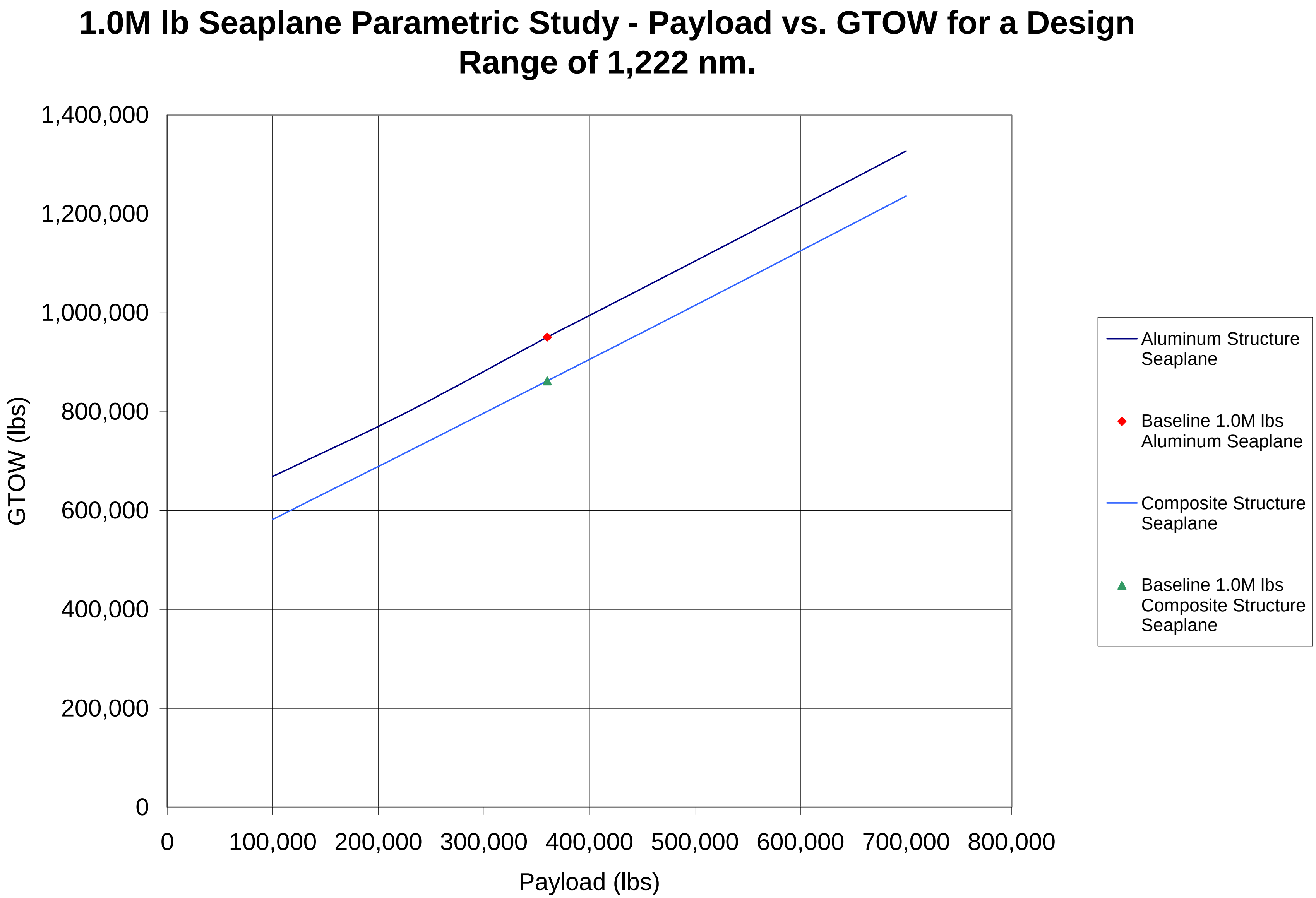



**Figure 83. 1.0 M lb. Seaplane with an all aluminum and all composite structure: Payload vs. GTOW**

# 4.0 RESULTS

The results of the parametric comparisons are shown in Database 2.1.1 through 2.1.5.

These curves show the basic parameters of the BFS 0.3 M lb., BFS 1.0 M lb., and the BFS 2.9 M lb. seaplanes all fall in line with the comparative data.

Base Case Lift Capacity

The methods of analysis for aerodynamics, weights, sizing, and flying boat design proportions have shown good agreement for the following rational mathematic analysis, in the Base Case Lift Capacity, section 2.2.

Improvement by Structural Weight Reduction

As explained in section 2.3.2.2 Strength of Composites, it is believed that improved aircraft can be fabricated using composite structure, rather than aluminum. Aluminum's resistance to salt water corrosion is very poor. Aluminum alloys must be coated in some fashion to eliminate and/or slow the process of corrosion. This is usually done with a sacrificial layer of material, such as paint or anodized coating. These protective barriers will need to be reapplied when the barrier is compromised. For aluminum alloys, one of the coating failure points is at the rivet holes. Even though sealants are used, eventually the slight movement of the metal skin relative to the rivet results in the holes expanding and letting in the salt water. A one piece, molded composite shell doesn't have this problem.

RANGE VS. PAYLOAD

The range versus payload trade studies for each aircraft featured two situations. The first situation was the increase in range using a retractable step, called "no step" in this report. The second situation used the weight savings for an all composite structure for increased payload capacity. The structural efficiencies from the use of composites were translated into the reduction in structural airframe weight. This weight savings was applied to the empty weight. Based on weight studies, it was decided that a 25% reduction in structural empty weight was reasonable. The reduction in empty weight did not include propulsion, equipment, systems, flight controls, landing gear, etc.

*Range vs. Payload Case 1: 0.3 M lb. Seaplane Effect of a Step*

Section 2.3.4.1.6 entitled "Chart – Thrust Required with a Fixed Step and with a Retracted Step" for the 0.3 M lb. seaplane shows the thrust required, thrust available, and max range points at a cruise altitude of 20,000 ft for a seaplane with a fixed step and with a retracted step. The results are as follows:

0.3 M lb. Seaplane
With a Fixed Step: M = 0.58 $C_{do}$=0.023000, Thrust Required = 18,610 lb.
With Retracted Step: M = 0.58 $C_{do}$ = 0.02167, Thrust Required = 17,802 lb.
The difference in $C_{do}$ = 0.00133, or 1.33 counts of drag.

Section 2.3.4.1.7 entitled "Range Payload with a Fixed Step and with a Retracted Step" for the 0.3 M lb. seaplane shows the effect of the step on the range of the seaplane. The effect of the step on range is as follows:

0.3 M lb. Seaplane

| | |
|---|---|
| With a Fixed Step: | Range = 6,576 nm. |
| With a Retracted Step: | Range = 6,765 nm. |
| Difference: | 189 nm. |

The seaplane with a retracted step in cruise flight can extend its range 189 nm. This is shown in Figure 52, page 88.

Maximum Cruise Speed Increase
The drag improvement from the no step condition will cause a change in the maximum cruise speed possible. The resulting speed increase from the fixed step condition to the retracted step condition is 15 knots.

*Range vs. Payload Case 1: 1.0 M lb. Seaplane Effect of a Step*
Section 2.3.5.1.3 entitled "Chart – Thrust Required with a Fixed Step and with a Retracted Step" for the 1.0 M lb. seaplane shows the thrust required, thrust available, and maximum range points at a cruise altitude of 30,000 ft. for the seaplane with a fixed step and with a retracted step. The results for thrust required are as follows:

1.0 M lb. Seaplane
With a Fixed Step: M = 0.7 $C_{Dtotal}$ = 0.0203, Thrust Required = 50,058 lb.
With Retracted Step: M = 0.7 $C_{Dtotal}$ = 0.0193, Thrust Required = 47,594 lb.

The difference in $C_{do}$ = 0.0010, or 1.00 count of drag.

Section 2.3.5.1.7 entitled "Range Payload with a Fixed Step and with a Retracted Step" for the 1.0 M lb. seaplane shows the effect of the step on the range of the seaplane. The effect of the step on range is as follows:

1.0 M lb. Seaplane

| | |
|---|---|
| With a Fixed Step: | Range = 8,936 nm. |
| With Retracted Step: | Range = 9,399 nm. |
| Difference: | 463 nm. |

The 1.0 M lb. seaplane with a retracted step in cruise flight can extend its range 463 nm.
This is shown in Figure 63, page 101.

Maximum Cruise Speed Increase

The drag improvement from the step condition will cause a change in the maximum cruise speed possible. The resulting speed increase from the fixed step condition to the retracted step condition is 3 knots.

*Range vs. Payload Case 1: 2.9 M lb. Seaplane Effect of a Step*

Section 2.3.5.1.6 entitled "Chart – Thrust Required with a Fixed Step and with a Retracted Step" for the 2.9 M lb. seaplane shows the thrust required, thrust available, and maximum range points at a cruise altitude of 30,000 ft. for the seaplane with a fixed step and with a retracted step. The results for thrust required are as follows:

2.9 M lb. Seaplane

With a Fixed Step: M = 0.7 $C_{Dtotal}$ = 0.0249, Thrust Required = 131,696 lb.
With Retracted Step: M = 0.7 $C_{Dtotal}$ = 0.0241, Thrust Required = 127,413 lb.

The difference in $C_{do}$ = 0.0008, or 0.80 count of drag.

Section 2.3.5.1.7 entitled "Range Payload with a Fixed Step and with a Retracted Step" for the 2.9 M lb. seaplane shows the effect of the step on the range of the seaplane. The effect of the step on range is as follows:

2.9 M lb. Seaplane

| | |
|---|---|
| With a Fixed Step: | Range = 10,601 nm. |
| With Retracted Step: | Range = 11,018 nm. |
| Difference: | 417 nm. |

The 2.9 M lb. seaplane with a retracted step in cruise flight can extend its range 417 nm.
This is shown in Figure 74, page 114.

Maximum Cruise Speed Increase

The drag improvement from the step condition will cause a change in the maximum cruise speed possible. The resulting speed increase from the step condition to the retracted step condition is 4 knots.

*Range vs. Payload Case 2: All Aluminum vs. All Composite Structure – 0.3 M lb. Seaplane*

Figure 55 entitled "0.3 M lb. Seaplane Parametric Curve – Range Payload for an all Aluminum Structure with Step and an all Composite Structure with Step" gave the following range results:

0.3 M lb. Seaplane – All Aluminum Structure: Range = 8,139 nm.
All Composite Structure: Range = 6,576 nm.
Difference = 1,563 nm.

Figure 55 also illustrates the weight savings from using an all composite structure versus an all aluminum structure. The vertical distance at the zero range point is the weight savings from using an all composite structure. The weight savings for the 0.3 M lb. seaplane is 19,318 lb, which was used as added payload. The result is the ability to carry more payload for the same distance, or to carry the same payload over a larger range.

The weight savings as applied to the 0.3 M lb. seaplane are as follows:

| Aluminum | Composite | Difference |
|---|---|---|
| GTOW = 260,003 lb. | 260,003 lb. | 0 lb. |
| Empty = 127,244 lb. | 107,926 lb. | 19,318 lb. |
| Useful = 132,759 lb. | 152,077 lb. | 19,318 lb. |

It can be seen that the useful load is increased by the same amount as the empty weight is decreased, or 19,318 lb. In this case, the useful load can be divided into payload or fuel for range.

In a similar fashion as the 0.3 M lb. seaplane, the BFS -1.0 M lb. and BFS – 2.9 M lb are as follows:

*Range vs. Payload Case 2: All Aluminum vs. All Composite Structure – 1.0 M lb. Seaplane*

Section 2.3.4.2.1, Figure 66 entitled "1.0 M lb. Seaplane Parametric Curve – Range versus Payload for all Aluminum Structure with a Step and an all Composite Structure with a Step" illustrates the following results:

1.0 M lb. Seaplane – All Composite Structure: Range = 11,431 nm.
All Aluminum Structure: Range = 8,936 nm.
Difference = 2,495 nm.

The weight savings in using an all composite structure instead of an all aluminum structure is 81,333 lb. This can be seen in Figure 66 as the vertical distance between the two curves at the zero range point.

The weight savings as applied to the 1.0 M lb. seaplane:

| Aluminum | Composite | Difference |
|---|---|---|
| GTOW = 950,600 lb. | 950,600 lb. | 0 |
| Empty = 470,432 lb. | 389,099 lb. | 81,333 lb. |
| Useful = 480,165 lb. | 561,501 lb. | 81,333 lb. |

Thus, the composite aircraft can fly 2,495 nm. more than the aluminum aircraft, or for the same range the composite aircraft can carry 81,333 lb. more payload than the all aluminum seaplane.

*Range vs. Payload Case 2: All Aluminum vs. All Composite Structure – 2.9 M lb. Seaplane*

Section 2.3.5.2.1 with Figure 77 entitled "2.9 M lb Seaplane – Range versus Payload for all Aluminum Structure with a Step and an all Composite Structure with a Step" illustrates the following results:

2.9 M lb. Seaplane – All Composite Structure: Range = 13,897 nm.
All Aluminum Structure: Range = 10,601 nm.

The weight savings in using an all composite structure instead of an all aluminum structure is 277,872 lb. This can be seen in Figure 77 as the vertical distance between the two curves at the zero range point.

The weight savings as applied to the 2.9 M lb. seaplane:

| Aluminum | Composite | Difference |
|---|---|---|
| GTOW = 2,923,076 lb. | 2,923,076 lb. | 0 |
| Empty = 1,430,000 lb. | 1,152,204 lb. | 227,872 lb. |
| Useful = 1,493,000 lb. | 1,770,872 lb. | 277,872 lb. |

Thus, the composite aircraft can fly 3,296 nm. more than the aluminum aircraft, or over the same range the composite aircraft can carry 277,872 lb. more payload than the all aluminum seaplane.

# 5.0 CONCLUSIONS

Any one improvement in seaplane design may not produce a large increment in perfomrance. Such increments will come through an accumulation of small improvements. Based on the studies here of early NACA reports from the 1940's and other works it was seen that one of the larger improvements (section 2.3.1.1) can come from drag reduction at the step. Analysis of the drag methods shows that drag coefficients for the step can vary from $C_{Dstep} = 0.0009004$ to $C_{Dstep} = 0.00036704$. This is between 6.24% and 2.55% of the total seaplane zero lift drag coefficient.

In this report one generic seaplane step was used, the simplest and easiest to analyze, so as not to have too many variables in the study (see section 2.3.1.1 Decrease Step Drag). The Raymer drag method was used to calculate the drag for the step. There have been many studies of different design steps with lower air drag, but this topic is beyond the scope of this report.

Another of the improvements that is worth consideration is the use of composites. Based on various studies in the literature, consultation with the US Navy materials engineers and structural engineers, military handbooks, and Dan Raymer's Aircraft Design book, it is estimated that the use of composites can obtain an approximate 15% weight savings. Composites can also reduce drag because of the possibility of achieving laminar flow.

The improvements in performance for the seaplanes appeared mostly in range. The improvement in the maximum cruising speed was slight. Increases in the maximum cruising speed ranged from a maximum of 15 knots to a minimum of 3 knots.

# 6.0 FOLLOW ON

## 6.1 FURTHER DRAG REDUCTION

Further investigation into drag reduction would include the following areas: chine reduction, decrease in other protuberances, laminar flow over the wing, drag reduction through the use of smooth composite surfaces.

## 6.2 RETRACTABLE TIP FLOAT

This design is already incorporated in the BFS 2.9 M lb. and BFS 1M lb. seaplanes. For the 2.9 M lb. seaplane the drag of the wing tip floats is $C_d = 0.00047$ (0.47 drag counts) in the retracted position at the wing tip. The drag was included in the overall drag coefficient. For the 1.0 M lb. seaplane the drag of the wing tip floats is $C_d = 0.00023$ (0.23 drag counts) in the retracted position at the wing tip. This is included in the overall drag coefficient.

## 6.3 WEIGHT SAVINGS: ACTIVE AEROELASTIC WING

It is possible that weight savings and maneuvering capability can be gained by using an active aeroelastic wing.

This research has been done by a joint project of NASA, the US Air Force Research Laboratory, and Boeing Phantom Works. In the past, engineers have been concerned about wing flexibility. A flexible wing may lead to flutter possibilities and control reversal. Flutter is an unwanted rapid oscillation of the surface caused by air loads. Now, it appears that a wing may be a better wing if it is more elastic. This improvement occurs by methods to allow the wing to twist in a controlled way. An article from http://www.aviationnow.com/awst gives an interesting account of creating an aeroelastic wing demonstrator from the preproduction McDonnell Douglas F-18A flight demonstrator in 1980. The F-18A preproduction aircraft had a supple wing at high speeds. When the ailerons were applied at high speeds, the forces on the control surfaces would twist the flexible wing in the opposite direction and negate the roll control action. The wing has consequently been stiffened for the production phase. The demonstrator will use servo tabs to twist the entire wing for roll control, instead of the use of ailerons.

This technology decreases the gross take-off weight over the entire design space studied. The indicated gross take-off reduction due to advanced aeroelastic wing is approximately 13%. The author thinks that this topic is worth studying, but there may be difficulties in implementing this technology on large aircraft.

## 6.4 SHORT TAKE-OFF UPPER SURFACE BLOWING

In 1978, a program was initiated to develop a proof of concept aircraft to fill the future need for an aircraft to operate at airports in congested areas with short runways (2,000 ft.– 3,000 ft.). This led to the concept of the quiet, short-haul research aircraft (QSRA). This program became a Boeing/NASA effort.

For this work a DeHavilland C-8A Buffalo airframe, modified with a propulsive-lift wing was chosen, see Figure 84. The QSRA is powered by four Lycoming TF-102 turbofan engines. The engines were located over the wing to provide upper surface blowing (USB), a technique to develop high levels of lift at low noise levels. Figures 84-87 show the features of the QSRA, such as a two-segment rudder, a T-tail elevator, spoilers, double slotted flaps (DSF), USB flaps, and drooped/blown ailerons.

Some results of this test are shown in Figure 88. It can be seen that lift coefficients as high as 11 can be achieved at an angle of attack of 25°. It is believed by the author that this ability would help enormously in short take-off on the water. This would make the seaplane much more versatile, enabling the seaplane to get in and out of lakes and rivers.

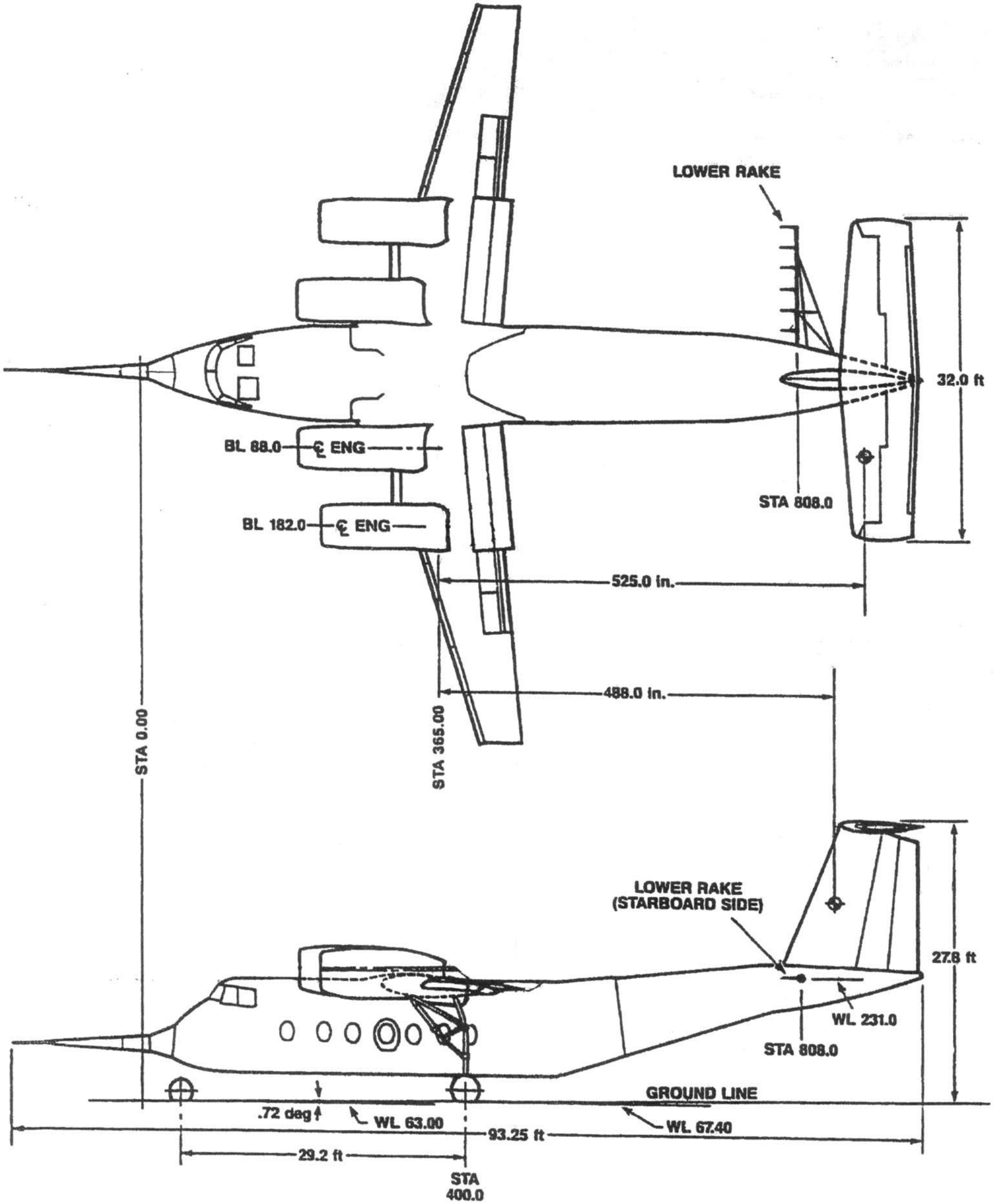
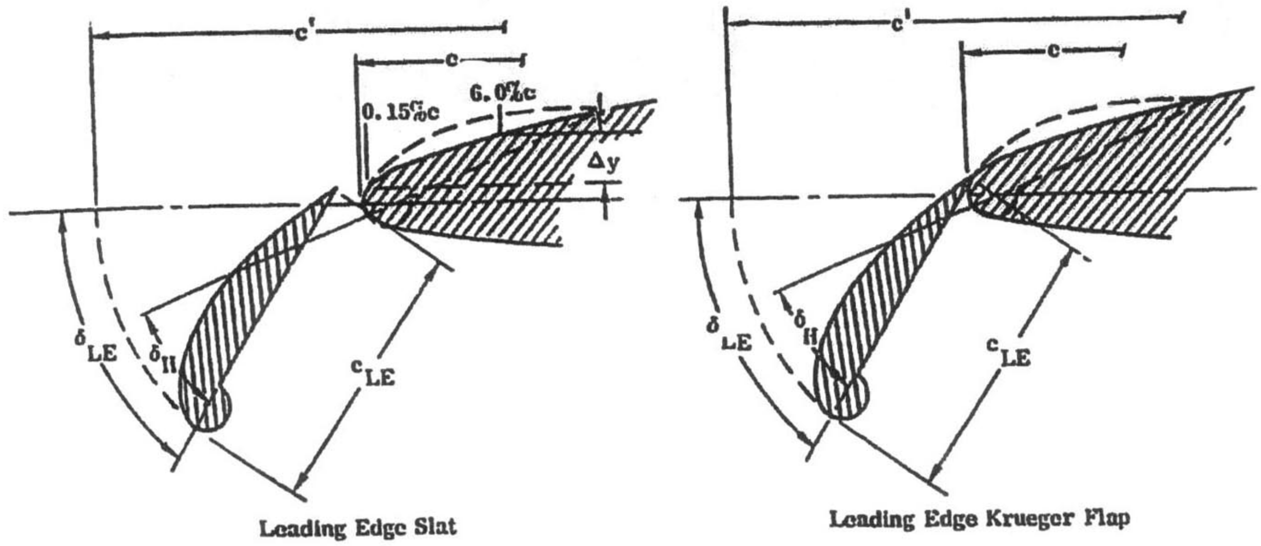
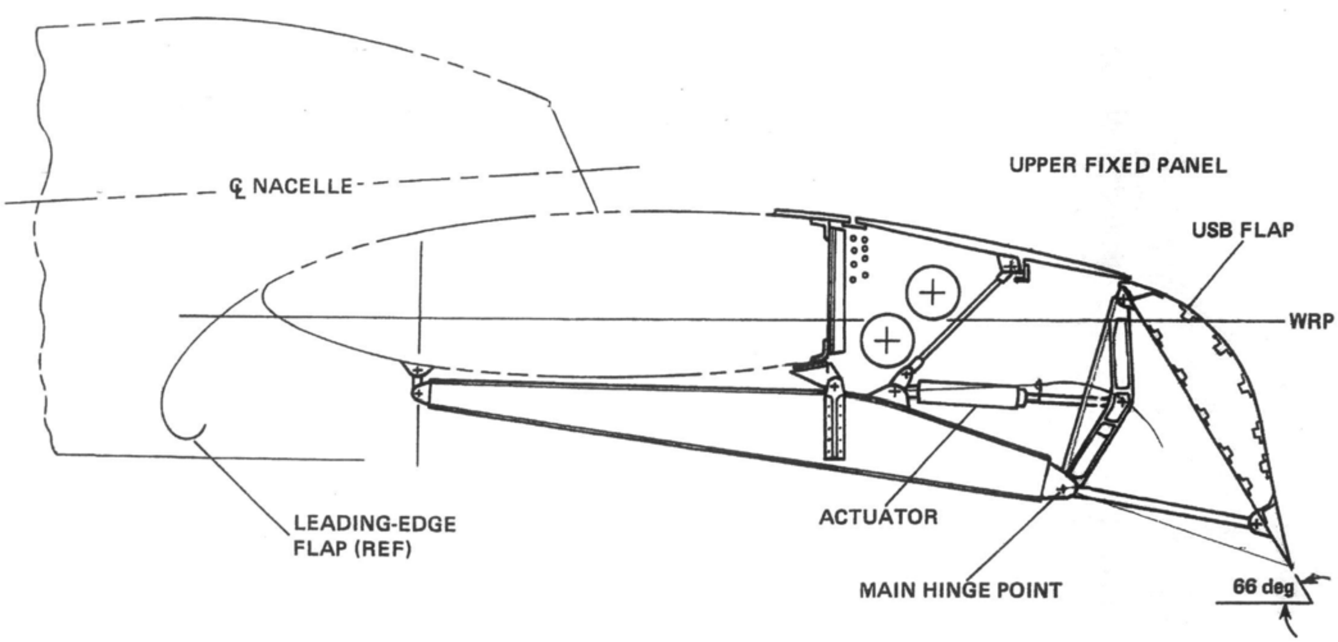



Figure 84. QSRA – 2 view.




Leading Edge Slat & Flap

**Figure 85. QSRA double slotted flaps.**




Center and inboard trailing-edge (USB) flaps

**Figure 86. QSRA upper surface blowing (USB) flap.**

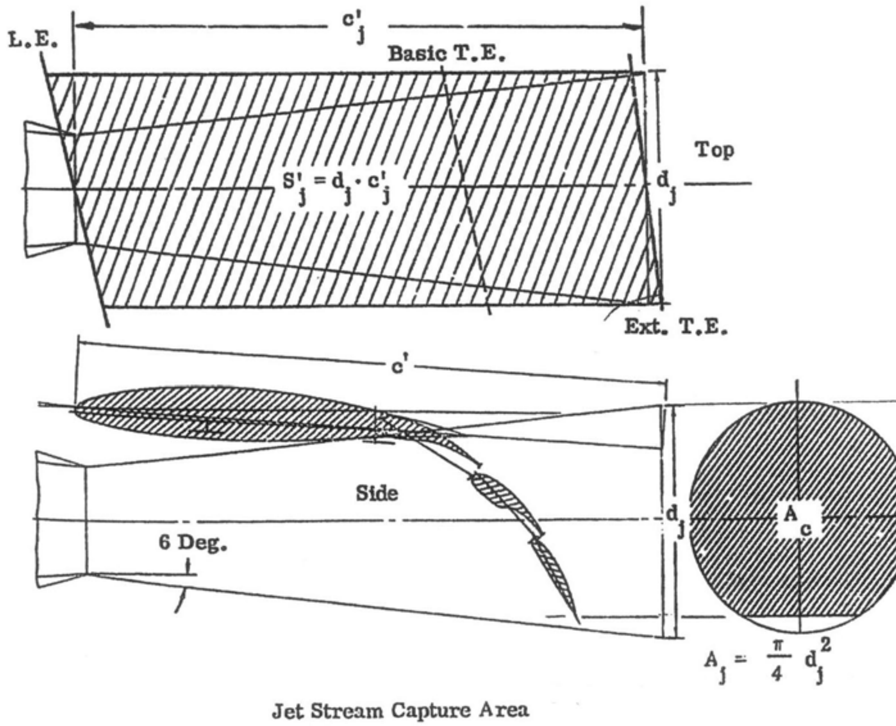
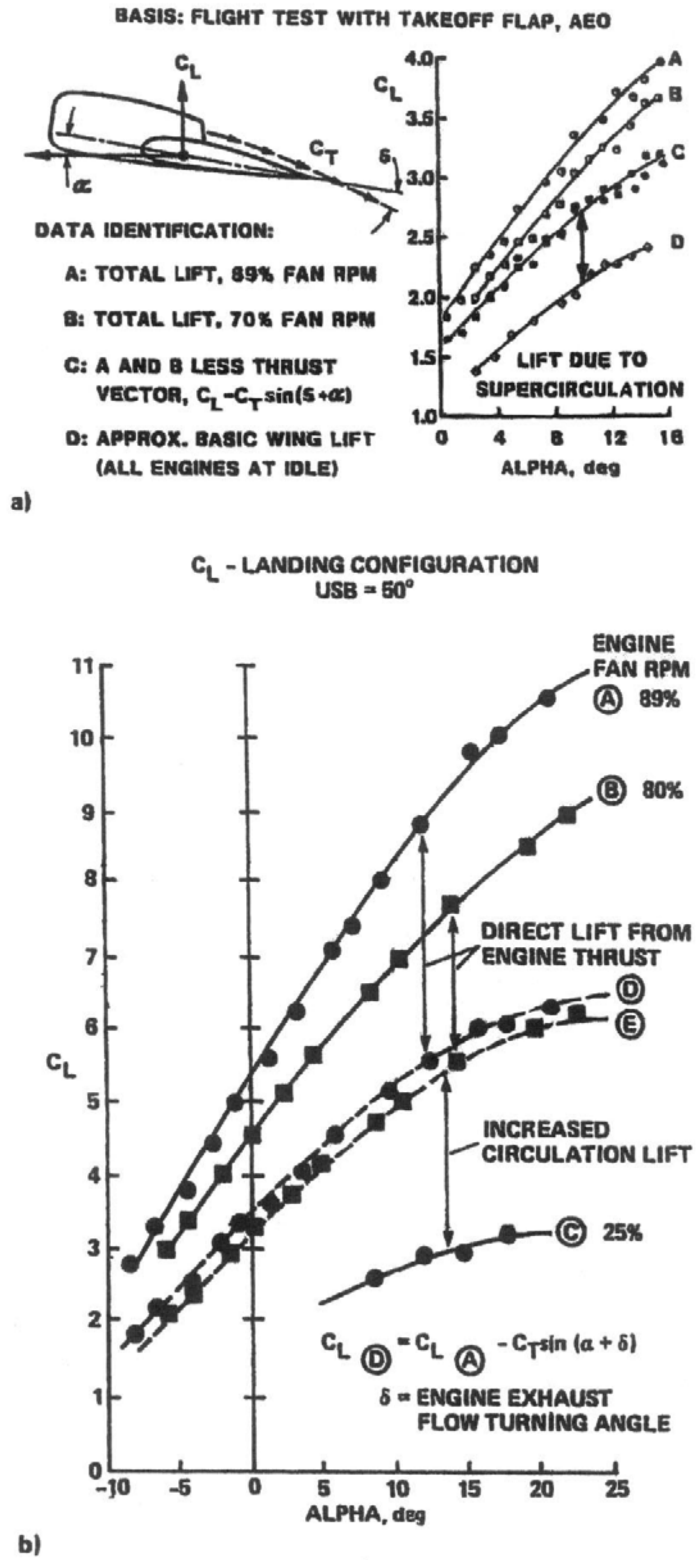



**Figure 87. QSRA Drooped/Blown Ailerons**




USB technology: wing lift buildup. a) Take-off, USB flap = 0°; b) approach, USB flap = 50°.

**Figure 88. QSRA lift improvement from upper surface blowing**

## 6.5 LAMINAR FLOW

Laminar flow is a condition on a surface where the skin friction is low. This low resistance to the flow allows the air steam to flow like layers above the surface. This type of flow is dependent on the Reynolds number, $R_n = \frac{\rho \cdot V \cdot L}{\mu}$. After a certain point, the flow may become turbulent. This point between fully laminar flow and fully turbulent flow is called the transition point. To obtain laminar flow, the surface must be aerodynamically smooth. The surface must be free of protuberances, such as rivet holes and structural seams in the surface.

The aerodynamics department at NAVAIR states that their studies show laminar flow should be achievable if the $R_N$ per foot is less than 1,000,000. If so, it is possible to obtain laminar flow up to 30% of the wing chord.

To achieve laminar flow the surface must be smooth. This can be achieved with composite bonded OML surfaces. For the present study laminar flow was not assumed. The wing transition point was assumed at the leading edge, so all the OML surfaces were assumed turbulent with a corresponding higher skin friction coefficient.

In the BFS 2.9 M lb. at a Mach number of 0.4 (250 kts at 30,000 ft.) laminar flow would be expected on the wing.

More studies should be done as to the potential of achieving laminar flow. Improvements in speed and range will be achieved.

## 6.6 OTHER IMPROVEMENTS

<u>Tiltwing</u>

With four turbofans and upper surface blowing, tilting the wing with the engines at about 30° may assist in a shorter take-off.

<u>Maneuverability of Seaplanes to a Sea Base dock</u>

A number of factors are involved in trying to dock a seaplane. Factors that should be considered are wind velocity and direction, wave size and direction, and tides. In order to load and unload cargo, the seaplane will need some means to climb the ramp. Consideration of night operations with landing and take-off will also need to be investigated. Seaplane pilots will need to be consulted.

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